EVOLUTION AS NATURE'S TRAJECTORY FROM COMPUTATION TO NARRATION

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ABSTRACT: Because the basis of physical order is temporal, evolution and narrative are naturally emergent and not inexplicable anomalies in a universe predetermined by timeless mathematical principles. The temporal world of life and consciousness has no place in classical physics but is perfectly at home in a quantum context. In and of itself an atom is the continuous computation of outcomes of potential interactions. The central mystery of quantum mechanics is cleared up by replacing measurement with temporal instantiation as the mechanism by which nature coughs up the determinate world of the senses. In contrast to the continuous time of natural computation – whether atomic, biological or symbolic – the time of classical physics is a succession of discrete instants. As Bergson noted, theorists tend to spatialize this succession into a static sequence. No such operation is possible with unbroken flux and the memory and purpose implicit in it.

KEYWORDS: Time; Information; Memory; Consciousness; Culture

1 INTRODUCTION

To understand nature we must understand time. To understand time we must start with consciousness. Unlike an event, which is present for an instant and then past, consciousness remains present. Because conscious experience is ongoing, we infer that previous experience is now past and that subsequent experience is now future. We infer past and future, but all we experience is presence, ceaseless happening, a "now" without beginning or end.

During a 1922 exchange with Henri Bergson, Albert Einstein dismissed the reality of a singular time in favor of a pair of times, one physical and one psychological, that is, one real and one subjective (Canales 2015, 46-48). Four years later Erwin Schrödinger developed wave mechanics and the time-dependent equation that governs the evolution of an unmeasured quantum system. The time of wave evolution turns out to be precisely that of consciousness. For an isolated system time is continuous presence, an indeterminate flux during which the quantum system entertains possible outcomes of a measurement. In contrast to the instantaneous present of classical physics, a present composed of possibilities need not pass. Like lungs that know only inhalation, the system steadily expands across potential configurations. Exhalation, the yielding of present to past, occurs only when the system is externally disturbed, for instance via measurement, which triggers the reduction of a multitude of superposed possibilities into a fleeting actuality. Whereas the atom's inner world is an enduring present generating a field of potentiality, the outer world inevitably imposes onto the atom a definitive state which is present only for an instant.

Before it can be measured, a quantum system must be prepared in its initial state. The fact that the measured state differs from the initial state is very curious since the only events that have taken place are the preparation and measurement themselves. From the standpoint of classical mechanics, nothing has happened in the interim, that is, no interaction with the system has taken place. Instead, according to quantum theory, the system has "evolved" in accord with a mathematical tool called the wave function.

As determined by the Schrödinger equation, the evolving wave function predicts the outcome of a measurement, but the prediction may or may not be correct. This is because the outcome of a quantum measurement is probabilistic. Only over a succession of measurements of identically prepared systems do the results conform, on average, to prediction. Taken at face value, the efficacy of the wave function means the atom, in the indeterminate and continuous time prior to the precise event, consists of a multiplicity of potential states and has no definitive state until measurement. The wave function is thus the human representation of the natural computation of possibilities intrinsic to the atom, i.e. *wave computation*.

Like an atom, the behavior of an organism is probabilistic. Whereas a robot will do as it was programmed, an organism has enormous latitude in how it responds to a given situation. If organisms engage in a kind of computation, it therefore resembles the probabilistic computation represented by the wave function rather than the deterministic activity of a computer. No less than any other aspect of the organism, the behavior of nerve cells follows from a kind of wave computation.

Granted, the skeptical neuroscientist might ask where this "wave computation" is located. Even the most exhaustive search of tissues and cells and macromolecules will reveal nothing that corresponds to a wave function. Yet this is equally true of quantum systems. The wave function, as Richard Muller puts it, is the *spirit* of the atom (2016, 204). That wave computation yields an outcome which is manifest to the eye upon measurement of the quantum system in no way renders it a tangible entity in space. As a function of an indeterminate and ongoing present, wave computation is always just prior to the precise instant of observation. Likewise, try as we might, we can never quite capture the underlying impulse of consciousness in a thought.

"Fluidity," writes Bergson, "is the immediate datum of experience" (1999, 44). In retrospect the flow of time can always be construed as a succession of discrete events. We can even imagine these events distributed across a virtual space, thereby reducing succession to mere juxtaposition. But the same cannot be said about current experience, which is pure flux, the ceaseless emission of the actual from the formless. As soon as an event takes place, it is past in the sense that it no longer participates in the inexhaustible dynamo of ongoing presence in which all experience is anchored. The essence of time, for Bergson, is the *hesitation* prior to determination. This is the time implicit in the Schrödinger equation, which governs the fluid computation of possibilities prior to the determinate outcome triggered by measurement.

To measure a quantum system is to momentarily convert it from a multiplicity of possible states to a single actual state. Translated into the Bergsonian worldview, measurement plays the role of the intellect, which demands a precise state at a precise time and excludes all other states. By contrast, the wave function plays the role of intuition, in which the observer, instead of trying to grasp the object of study from the outside, enters into sympathy with it. What is the atom in and of itself without the burden of external measurement? This is what Schrödinger achieved with wave mechanics.

Moreover, in keeping with the pre-measurement atom of quantum theory, Bergson characterized life not in the sense of determinate bodies but as "an immensity of potentiality" (1911, 258). Consciousness, he wrote, "measures the interval between representation and action" (1911, 145), that is, between wave computation and the determinate present, which he regarded as the "very materiality of our existence" (Ansell Pearson 2002, 178). Yet we not only perceive what is tangible but remember and anticipate. Every moment of life thus entails two aspects, one actual and one virtual, one which is present to the exclusion of past and future and one which embraces them in the form of memory and potentiality. We see not only potentiality in wave computation but the endurance of past into present as revealed in quantum entanglement, whereby the previous interaction of a pair of systems continues to manifest over time as correlated states of those systems.

Despite the fundamental agreement between his philosophy and the findings of quantum mechanics, Bergson never recognized that his time-based metaphysic had been vindicated by science. In part this followed from his belief that scientific investigation is a work of pure intellect and therefore incapable of uncovering metaphysical truth (1911, 195, 344). But it also reflects a shortcoming in his philosophy of time, specifically his claim that time is strictly continuous, i.e. that "real time has no instants" (1999, 36). A succession of discrete instants is a fiction generated by the intellect operating without the aid of intuition. "Things are constituted by the instantaneous cut which the understanding practices, at a given moment, on a flux" (1911, 249). Note the use of the word "cut." This term would later resurface as the "Heisenberg cut" between the wave-mechanical atom and the classical world of well-defined objects. For Heisenberg, however, far from a product of the intellect, the wave-mechanical world cuts out with the *physical* intervention of a measuring device. Thus the instant at which an atom takes on a precise position is no less real than the flux of wave computation preceding measurement. Heisenberg accepted the reality of the continuously evolving potential of the wave-mechanical state in the unmeasured atom *and* the instantaneous state upon measurement. Having committed to the unreality of the instant, Bergson could never accept such a view.

Yet his underlying point about the operation of the intellect is valid. Though a celebrated professor, nothing was ever academic for Bergson. The point of philosophy is not, like science, to gain mastery over nature but to know how to live, to be human. At its essence life is continuous creation. This realization is undermined by the imperative of the intellect to abstract from the flux a sequence of states from which to construct a static facsimile of the world, an excellent approach if you want to make machines but at the cost of distorting our sense of reality. A biology based on classical mechanics cannot distinguish the creative adaptation undertaken by the organism from the passive adaptations dictated by its environment. If the world is nothing but a great machine, the cause of every event, physical or biological, lies in a previous event in a deterministic chain devoid of creativity or genuine novelty. In opposition to the dictates of the science machine, Bergson argued that our human task is to make our home in that fluid moment of hesitation prior to actualization, for only in this moment is there freedom and humanity and meaning (1911, 144-45).

Science is a means of obtaining objective knowledge, which can be used to advance human interests as much as mechanizing thought and society. Granted, the culture of science can be obnoxiously dismissive of any belief that fails to conform to precise mathematical formulation, but the standardization of human thought is inherent to culture generally, not just scientific culture. When Bergson enthusiastically embraced French patriotism at the outset of the original World War – when he justified war by associating France with conscious creativity and Germany with lockstep automatism – he was just one more tasty morsel for Moloch, the beast that occasionally stirs from the depths of the human heart to feast on the minds of thinkers and the blood of soldiers.

In this article I examine biological and cultural evolution, setting the stage with the temporal basis of quantum mechanics and carrying on to self-organized chemical systems, the biological systems known as organisms and finally human consciousness and its unplanned offspring, culturally-mediated irrational systems. The thread that ties it all together is continuous presence, the wave of creation always just prior to tangible existence.

2. OVERVIEW OF QUANTUM MECHANICS

2.1 Origins

The object of study of classical physics is the physical world. If you want to know the velocity of a crow, you observe its positions over time and calculate its speed and direction. How quaint this must seem to the quantum physicist. When it comes to microphysical systems such as atoms and photons, the object of study is no longer the physical world but a complex mathematical entity called the state vector, better known as the wave function. When the relevant variables are entered in, the wave function determines the likely outcome of a measurement. Prior to measurement there are no positions or velocities or even particles, only a wave function, which cannot itself be measured or expressed as a classical variable. The measured quantity exists only at the moment of measurement, the outcome of which determines the starting point of renewed evolution of the wave function. In the end what we observe is not a physical object but only a "phenomenon" that arises from the interaction of the quantum system and the device by which we measure it.

Why must we tolerate this probabilistic intermediary between the world and our investigation of it? The trouble began with Planck's discovery that the oscillation of a charged particle is limited to specific frequencies. Yet this unexpected factor, as Bohr later realized, explains the stability of the atom. Whereas charged particles, according to classical theory, are free to oscillate at any frequency, atomic investigation revealed that an electron, on this basis, will eventually spiral into the atomic nucleus. Instead the electron adheres to a set of discrete possible frequencies, the lowest of which – the ground state – equals Planck's constant (Ney and Albert 2013, 1-2). Since the spectrum of discrete frequencies, in both matter and light, corresponds to the spectrum of discrete values of energy, Planck's constant is the lowest amount of energy allowed by nature. Unable to drop below this energy level, the electron remains aloft around the nucleus (Smolin 2019, 60).

What is good for the atom is deeply problematic for physics. Defying common sense, the electron never occupies the space between orbits. Instead, when a photon enters the atomic system and thereby augments its energy, the electron instantaneously occupies a higher orbit. The same applies to the position of an atom in space. At odds with the continuity assumed in classical physics, the "quantum leap" or *quantum of action* is fundamentally discontinuous.

The Schrödinger equation, the master equation of quantum mechanics, translates the mass of each particle comprising a quantum system – and the forces acting between those particles – into a spectrum of resonant frequencies. Inputting an electron and a proton, for instance, yields the frequency spectrum of a hydrogen atom. Schrödinger's formalization of quantum mechanics is known as wave mechanics because each resonant frequency corresponds to a wave. Occasionally the system is in a pure state, which resembles a single note struck on a piano, in which case the outcome of a measurement of energy or momentum is given by the wave function. But when the system is in a mixed state, which resembles a chord of several notes struck together, the outcome of measurement is probabilistic. In this case, squaring the amplitude of the wave function yields the probable value, upon measurement, of a given quantity such as the energy of a system or its position or momentum. Though each measurement gives a random outcome, over time the average result agrees with prediction (Smolin 2019, 31, 60-61).

The wave function, as Franck Laloë observes, "evolves gently, in a perfectly predictable and continuous way" (2019, 21). Just like classical waves, which are inherently continuous, the evolving wave function generates superpositions except that what is superposed is not matter but potential values of a variable quantity. Due to the quantum of action, the result of a measurement is an uncontrolled discontinuous jump from superposed values to a single value. The interaction of quantum system and measuring device generates an instant seemingly outside of time, that is, outside the smooth progression of wave evolution. As Laloë puts it (2019, 142), the measurement result occupies a space-time "bubble" unifying quantum system and measuring device. Regardless of which formalism is applied – Schrödinger's wave mechanics or Heisenberg's matrix mechanics – at the moment of measurement the interacting systems comprise an indivisible whole. The quantum of action disrupts the continuity of time in favor of the instantaneous melding, or "entanglement," of formerly distinct systems (Folse 1985, 118-19).

2.2 Complementarity

The unstated assumption of classical physics is that a physical system is distinct from the act of observing it. Bohr's principle of complementarity is necessitated by the instantaneous entangling, due to the quantum of action, of the system under study with the device that measures it. Unable to precisely distinguish what we are investigating from the means by which we do so, the classical ideal of objectivity fails (1985, 150-51). Though he stopped short of denying the intrinsic reality of the quantum object, Bohr noted that our classical concepts fail to capture it. If they did, the object would be in contradiction with itself (1985, 120).

To coordinate a quantum system in space-time is to resolve it as a particle. At a space-time point, light is a photon. But the energy of light is expressed in its frequency of radiation, rendering it wavelike. Since an object cannot be both particle and wave, these phenomena have no existence outside the context of measurement. This is the meaning of complementarity. Only when measuring for position or time (at an instant) is the system a particle, and only when measuring for momentum or energy is the system a wave (Bohm 1951, 130). The underlying reality is neither one nor the other. Rather than matter containing mutually contradictory aspects, observers generate complementary pictures of it (Folse 1985, 115-17).

By substituting "wave" with momentum and "particle" with position, we arrive at Heisenberg's uncertainty relation. Even in classical physics, momentum and position are conjugate parameters, precluding simultaneous definition. Moreover, measurement inevitably results in a disturbance of the system under study. This is not a problem for classical analysis because the disturbance can be calculated by way of the conservation of energy and momentum and thereby removed from the measurement result. As a result of the irreversible discontinuity introduced by the quantum of action, however, no mere calculation can restore the precise value of momentum once position has been measured and vice versa (1985, 92-93).

Bohr's case for complementarity was directed at Einstein and his partisans. Unable to reconcile himself with the idea that the results of measurement have no direct application to the object of study but concern only the interaction of the object with the measurement apparatus, Einstein characterized complementarity as the "abandonment of the concept of reality in physics" (Folse 1985, 145). Through a careful study of entanglement Einstein believed he had found a way to overturn Bohr's principle.

The quantum of action entangles systems when they interact. Electrons, for instance, are correlated in their spins following interaction. Even if we know nothing of the state of each electron, we know that one of them has a negative spin and the other has a positive spin. Quantum contrariness, which Einstein discovered, applies equally to momentum (Smolin 2019, 38, 43). Even without a measurement, we know that the momentum of one entangled electron is contrary to the momentum of the other. Since momentum includes direction of movement, if we know the position of one electron, we can determine that of the other.

Armed with this insight, Einstein presented his argument in a paper co-written with his colleagues Podolsky and Rosen. In essence, the EPR argument is that in the case of an entangled pair of systems, A and B, by measuring system A for momentum we know the momentum of system B, and by measuring system B for position we know the position of system A. Thus the entangled systems exhibit both position and momentum at the same time (Folse 1985, 147-48). Not only is complementarity overturned, but quantum theory is shown to be incomplete. Since the correlation of quantum states is instantaneous regardless of how far apart the systems have traveled following entanglement, the coordination of the results of each measurement cannot involve the transmission of information from one system to the other, as this would violate the speed of light as the maximum signaling speed. Therefore, at the moment of interaction – that is, prior to traveling apart from each other – the systems evidently conspired on how each one would respond to a measurement at a later time (Laloë 2019, 64). This quantum conspiracy theory, known as "hidden variables," has no place in orthodox theory, which is just as well since the existence of local hidden variables has been decisively refuted by successive experiments testing Bell's theorem on nonlocality (2019, 86, 99, 153).

As Schrödinger discovered, upon interaction formerly autonomous systems can be represented by a single wave function (2019, 190). So long as no subsequent interactions take place, the systems can drift apart any distance, even to the point of spacelike separation, and remain instantaneously correlated in their states (2019, 237). The wave function appears to be indifferent to space-time. This is unproblematic from Bohr's perspective, according to which the wave function is simply a mathematical expression of our knowledge of quantum systems (Faye and Folse 2017, 115, 120). The fact that wave mechanics gives a range of values of momentum or position in no way means the quantum system actually has any of those values. The probabilistic values encoded in the wave function are merely abstractions until a particular value is actualized via interaction. So long as we measure the momentum of A alone, then B has no actual momentum, only an abstract momentum, and so long as we measure the position of B alone, then A has no actual position. Granted, once we measure the momentum of A, we know how a measurement of B will result, but until the actual measurement of B takes place, it has no determinate momentum. Einstein's mistake, according to Bohr, was to grant the quantum system physical reality "independently from observation" (Folse 1985, 149-51).

Complementarity is inescapable in light of the quantum postulate, according to which the nonzero value of Planck's quantum of action implies the failure of the classical unification of space-time observation with causal (energy-momentum) analysis. Though we notice it only with respect to actions small enough to be in range of Planck's constant, in theory the quantum of action applies universally (Laloë 2019, 141). Einstein's rejection of complementarity stemmed from his belief that a purely contingent fact such as the quantum of action cannot constitute a foundational principle. As to his own use of the quantum in his successful interpretation of the photoelectric effect, Einstein regarded it as a purely heuristic placeholder until the arrival of a satisfactory substitute (Folse 1985, 153). Bohr was defending not just complementarity but quantum theory itself.

2.3 Wave Function Collapse

Far from trying to explain the basis of existence, Bohr sought an interpretation of quantum mechanics that facilitates research. But we are not machines. We want to understand, not just operate. Inevitably theorists tried to account for our experience of a world composed of objects bearing definite values of properties, that is, to resolve what Alyssa Ney calls the macro-object problem (Ney and Albert 2013, 26). How does a superposition of potential values of a given variable, as encoded in the wave function, provide the basis of tangible macroscopic objects?

The result was orthodox quantum mechanics, proposed by Dirac and brought to fruition by von Neumann (Whitaker 2006, 195). In contrast to Bohr, who never spoke of a quantum world and simply assumed a classical world, von Neumann began with the recognition that the fundamental reality is quantum and sought to extract the world of the senses from this underlying stratum. Rather than treat a measuring device as innately classical, he subjected it to a quantum-mechanical analysis, assigning it a wave function and a superposition of probabilistic states (Laloë 2019, 24). The trouble is that each superposition of possibilities, according to the Schrödinger equation, leads only to another such superposition. At no point does wave evolution yield to a classical world. In order to explain our perception of macro-objects, von Neumann proposed that the wave function sometimes collapses, abruptly reducing a range of possible states to a single actual state. He referred to the collapse of the wave function as "Process 1" in contrast to "Process 2," which is the isolated quantum system as governed by its wave function. The deterministic evolution of the wave function, Process 2, is a linear progression from one superposition to the next. Only with Process 1 is there a nonlinear jump from superposed values of a given variable quantity to a single definite value of that quantity (Ney and Albert 2013, 26-27).

The challenge is to explain why the wave function collapses. When a measurement takes place, why should the indicator point at a particular outcome? Why not point simultaneously at every possible outcome? To rely on the classical concept of measurement is to assume a classical world from the outset, the very thing that must be placed in a quantum context.

To explain wave function collapse, von Neumann suggested that Process 2 terminates when a definitive result of measurement registers in the mind or "abstract ego" of the experimenter (Whitaker 2006, 198). Wigner interpreted von Neumann to mean that irreducible consciousness generates classical definitude from quantum superposition (Ney and Albert 2013, 28). By this view the linear progression of the wave function continues through every stage of measurement, from detection of the electron to the movement of the indicator to the transmission of light from the indicator to the retina of the scientist, even to the processing of the visual image in the occipital lobe of the scientist. Only when the scientist becomes *conscious* of a definitive result of the measurement has the wave function collapsed, that is, Process 2 has yielded to Process 1. Precisely because consciousness is not physical, it can intervene in an otherwise unimpeded expansion of superposition from micro to macro, forcing the collapse of wave evolution.

To rely on a nonphysical entity to resolve a problem of physics is ultimately no more satisfying than Bohr's avoidance of the problem altogether. Consciousness is invoked merely as a *deus ex machina*, descending from the heavens to put an end to an otherwise insufferable drama. At last we can stand up and walk out of the theater, but do we have a real answer?

2.4 Potentia and Event

Bohr treated the wave function as an abstraction and neglected the question of the independent reality represented by this mathematical construct. Orthodox quantum mechanics evades the issue by attributing wave function collapse to consciousness and leaving unresolved the ontological status of either entity. Seeking to understand what really happens in an atomic event, Heisenberg made a tentative first step toward a genuine resolution (1958, 50).

In statistical mechanics, writes Heisenberg, probability "means a statement about our degree of knowledge." The wave function, on the other hand, signifies "something more than that… a quantitative version of the old concept of 'potentia' in Aristotelian philosophy." Though the wave function is obviously a mathematical artifact of human thought, the accuracy of its predictions indicates that it represents something real, namely a probability wave. According to Heisenberg, "the probability wave [introduces] something standing in the middle between the idea of an event and the actual event, a strange kind of physical reality just in the middle between possibility and reality" (1958, 40-41).

The wave function represents not a "course of events" but a "tendency of events" (1958, 46). If tendency is just as real as actuality, measurement merely marks the transition from one reality to another. By invoking the reality of *potentia*, which Aristotle defined as matter without form, we can make sense of the outcome of a measurement. Rather than create the tangible system out of thin air, the measurement merely transposes it from an equally real but intangible or unformed system. Thus quantum mechanics, as Heisenberg notes, turned science away from the 19^{th} century materialist trend (1958, 145-147).

Wave function collapse occurs "when the transition is completed from the possible to the actual. The probability function, which covered a wide range of possibilities, is suddenly reduced to a much narrower range by the fact that the experiment has led to a definite result, that actually a certain event has happened" (1958, 142). We cannot say what happens to the quantum system between measurements, as it consists solely of the potential for something to happen. Only by performing a measurement can "we change over again from the 'possible' to the 'actual.'" Indeed, "the term 'happens' is restricted to the observation" (1958, 47, 52). Despite the apparent subjectivity of observation, Heisenberg in no way suggests that quantum mechanics includes "the mind of the physicist as a part of the atomic event." No need to invoke a role for consciousness when the interaction of quantum system and measuring device is the event that triggers the irreversible transition from potential to actual (1958, 54-55).

Heisenberg's approach puts Bohr's response to EPR in a new light. Rather than claim that the position of the unmeasured entangled system is merely an abstraction, we may now accept its reality but only in the sense of intangible potentiality. Given EPR, the probability wave is not only intangible but nonlocal. Upon collapse of the probability wave, the parts of the quantum system can actualize anywhere in space at any distance from each other.

Yet the central question remains unanswered. Why does a measurement constitute a tangible event given the fact that a measuring device, according to the linear Schrödinger equation, ought to occupy a superposition of possible states rather than a definitive state? When the measuring device interacts with the quantum system under investigation, the two systems ought to become entangled under the direction of a single probability wave. Why do we observe a single outcome of the interaction instead of superposed possible outcomes?

Heisenberg himself cast doubt on his proposal by pointing to the necessity of configuration space in plotting the evolution of the wave function of a many-particle system (1958, 130). Classical space is limited to three dimensions. The high-dimensionality of configuration space – three dimensions for every particle comprising the system – suggests that the probability wave is indeed a mathematical abstraction with no claim on objective reality.

3. QUANTUM REALISM

3.1 Two Postulates

As Laloë points out, the divide between the evolution of the wave function and its collapse indicates that orthodox quantum theory is not perfectly defined by its postulates (2019, 22). To resolve this problem, we begin with a time postulate.

Implicit in Heisenberg's distinction between potentia and event is a twofold concept of time. As represented by the smoothly evolving wave function, the time of the probability wave is continuous. The time of measurement, by contrast, is a discrete moment in which the quantum system reveals a well-defined value of the measured quantity. Any act, including the act of measurement, is present for an instant and then past. In contrast to the determinate outcome of measurement, the indeterminate state of an unmeasured quantum system occupies an indeterminate and unbound present. Rather than recede into the past, the ill-defined present of the probability wave remains ongoing so long as the quantum system remains isolated. Because no interaction takes place – that is, nothing *happens* – there is no definitive event which, in the following well-defined moment, is past.

The point at which an evolving superposition of possible states yields to a definitive state is known as the Heisenberg cut. The question that has long haunted theorists is where to apply to this cut (Laloë 2019, 26). When in the process of measurement does superposition cut out? The question is rendered meaningless once we recognize that the instant itself is the cut and that the measurement process entails many instantaneous events and therefore many cuts. These include not only the atomic event itself such as radioactive decay but the resulting "blip" on a readout, the emission of light from the readout, the absorption of light in the retina, the electrical signal triggered at the retina and neural activations in the visual system of the observer. Every one of these events implies a temporal discontinuity that eliminates, in the confines of that instant, the evolution of possibilities.

Granted, not every interaction forces a discontinuity in wave evolution. According to Bohr, quantum measurement requires a well-defined experimental arrangement that translates the interaction of quantum system and measuring apparatus into an observable state (Laloë 2019, 22). The implication is that only carefully crafted interactions produce classical states. Yet we are confronted, at every moment, by a classical world comprising not only everything we observe but the organs by which we do so. Clearly the right kind of interaction in no way depends on scientists conducting well-designed experiments. Nature produces effortlessly everywhere and at all times an effect which scientists expend extraordinary effort to replicate with quantum measurements. As Shimon Malin argues (2001, 127-28), the right kind of interaction is the one that forces the quantum system to make a *choice* among its various possible states. If an electron is about to collide with a screen, it must "choose" a particular location on the screen and not any other. As long as no choice is forced upon it, the electron remains in its default wave state.

From the standpoint of time, the collapse of the probability wave is the transition from the enduring indeterminate present, i.e. fundamental time, to the determinate but fleeting present of subsidiary time. Each instant emerges from the temporal continuum indicated by the Schrödinger equation. Whereas tangible existence is composed of a rapid succession of spatially extended material configurations, fundamental time is limited to *potential* configurations and therefore has no need of classical space. The potentiality space associated with fundamental time is formulated in quantum theory as either Hilbert space or configuration space, each of which contains an unlimited number of dimensions (Ney and Albert 2013, 5). From the standpoint of space, what collapses upon interaction is simply the number of dimensions. Heisenberg need not have worried about the reality of potentiality. If classical space is real, by necessity so is the high-dimensional potentiality space from which it emerges moment to moment.

When collision between an atom and a macroscopic object is imminent, the wave function of the atom gives the possible locations of impact. In accord with the Born rule, squaring the amplitude of the wave function gives the probable outcomes (Laloë 2019, 9). But we cannot know which outcome actually takes place until potentiality space reduces – for an instant – to classical space. Not just human investigators but *nature* demands a definitive outcome of conflict. The collapse of potentiality space into classical space at an instant is how nature retains a single timeline. As we look into the past, we find only one succession of events leading to the present. Without nature's method of pruning the tree of time, we would look back at an impenetrable tangle of histories.

Implicit in the collapse of potentiality into actuality is the prohibition of multiple actualities. Possibilities can multiply infinitely, but the tangible world is singular. In addition to the time postulate, quantum mechanics therefore requires a *cosmic unitarity* postulate. Instantiation is nature's mechanism of preventing the evolution of superposed possibilities from spilling over into multiple worlds.

Whereas wave evolution – in accord with the Schrödinger equation – is linear and deterministic, instantiation is an uncontrolled jump to a probabilistic outcome. To maintain a single world, nature routinely sacrifices time-reversible determinism in favor of irreversible probabilism.

To account for the continuous evolution of the wave function, we postulate continuous time in addition to the classical time of successive instants. To account for wave function collapse via instantiation, we postulate cosmic unitarity as a fundamental property of nature.

3.2 Instantiation and Translation

Given that quantum mechanics is fundamental and classical mechanics approximate, why does a macroscopic object such as a measuring device occupy a classical state instead of a wave state even before the act of measurement?

If an electron is hurtling toward a screen, both the electron and the atom it encounters in the screen instantiate upon collision. But the atom is already in a classical state, repeatedly instantiating due to its close proximity to a very large number of other atoms. As a result of electromagnetically mediated interactions, atoms comprising a macroscopic object are constantly forced to choose particular states rather than remain in superposition. In essence, the atoms continually "measure" each other, defining a succession of well-defined moments in the context of which each atom bears well-defined values of its variable properties. A measuring device is thus always primed to collapse the probability wave of whatever quantum system with which it interacts. Because the device instantaneously absorbs the system into classical space, the probability wave of the system literally has no time to absorb the device into potentiality space. Against the background of fundamental time, the cinematic succession of instants is the basis of not only the measuring device but the classical world generally.

Our continual sensory confirmation of a classical world tells us that subatomic systems are frequently in a state that enables them to serve as the "building stones of atoms," in Bohr's words, and by extension macroscopic matter (1987, 21). The salient question, as we learn from quantum computing, is not how to trigger wave function collapse but how to *prevent* its collapse in a matter-rich environment. Not only conflicts between quantum systems but electric and magnetic fields threaten to disrupt the wave-mechanical state that gives quantum computing its edge over classical computing (Lewton, 2021).

The photoelectric effect, as Einstein surmised, takes place when a photon strikes a metal surface and thereby frees an electron from the metal. At the instant of contact both systems occupy their particle state, for only in this state can energy be exchanged in a discrete amount. Whereas identifying light at a space-time point renders it into a photon, identifying its energy level renders it into a wave. In the first case the measurement takes place at an instant. In the second case, since frequency cannot be established instantaneously, measurement entails duration. Likewise, the wavelength that reveals the momentum of a system has no existence in the confines of a space-time point (Bohm 1951, 92, 131). Though we may assign a precise value of momentum to a moving system at an instant, far from a product of instantiation this is merely an abstract instant projected onto the system by the observer. The actual momentum, meanwhile, is smeared across many instants.

When the motion of an electron places it in conflict with an immovable screen, the electron must strike at a particular spot, collapsing its wave function from many possible locations to one. The screen has effectively measured the electron's position. By contrast, to directly measure the momentum of an electron means establishing its wavelength, which requires unimpeded motion. Because conflict is avoided, the collapse of the wave function has a radically different meaning in this case, signifying *not* the interruption of wave evolution but merely the elimination of uncertainty in the mind of the observer.

To narrow down position to a single value is to bring out the instantaneous at the expense of the ongoing and therefore to sacrifice precise knowledge of momentum. To narrow down momentum to a single value is to bring out duration at the expense of instantaneity and therefore to lose precise knowledge of position. Heisenberg, however, does not seem to have recognized the temporal basis of the uncertainty principle or to have connected it with his implicitly temporal conjecture on the equal reality of potentiality and actuality.

That wave evolution can be interrupted, such as when an electron strikes a screen, in no way means presence ceases to be ongoing. That nature has no "time out" is already implicit in the conservation laws of momentum and energy. Though instantiation is the departure of the quantum system from the ongoing to a discontinuous present bearing a determinate position, the temporal background remains. Only insofar as instantiation is set against the background of continuous presence are discrete events causally associated. Rather than negate background, foreground complements it.

Complementarity is essential to quantum theory because the most fundamental object of quantum inquiry is not matter or light but time, and time cannot manifest as both continuous and discontinuous in the same measurement. In the case of an evolving probability wave, time is continuous. Measurement either extends the continuity of fundamental time into the classical domain (momentum and energy) or momentarily dislodges the quantum system from the underlying ongoing present (position and instant). Wave evolution either smoothly translates into a classical wave on a field or instantiates as a particle of time, in the context of which matter is by necessity particulate.

Bohr developed the principle of complementarity in response to the clash between observation and causal analysis. Coordinating the quantum system in space-time generates a temporal discontinuity, snipping the deterministic thread that explains the system's current state according to its past state (1987, 11). Causation requires, on the one hand, temporal continuity and, on the other hand, distinct moments such that the first is the cause of the second. The only way for this to work is if each moment has no independent reality but merely expresses the temporal continuum from which it emerges. Because the instant is inseparable from the deeper temporal context, the continuity of wave evolution not only instantiates into precise positions at precise moments but translates into causal flow as manifest in momentum, electricity, electromagnetism and gravity.

3.3 Agreement with Experiment

The intrinsic reality of time as ceaseless presence – and, by extension, the reality of potentiality – receives experimental confirmation from a variant of the Mach-Zender interferometer experiment (Laloë 2019, 37-38).

In the basic experiment particles are emitted, one by one, into an interferometer. Strictly speaking, of course, "particle" is incorrect since each quantum system passes through a beam splitter that separates it into two wave packets, i.e. waves of potentiality, which are channeled into different arms of the interferometer and then redirected by mirrors to a convergence point beyond which is a pair of detectors. The interferometer is set up such that the waves destructively interfere at one of the detectors, D2, with the result that every particle registers at the other detector, D1. Only at the instant of detection is the quantum system actualized as a particle with a precise location. Prior to this the system consists only of probability waves.

In the variant of the experiment, an "opaque object" is inserted into one of the two arms of the interferometer and blocks the probability wave in that arm, thereby eliminating the destructive interference and allowing the quantum system to instantiate as a particle at D2. As Laloë points out, the measurement of a particle at D2 seems to indicate two contradictory effects. On the one hand, the quantum system has been absorbed by the opaque object. On the other hand, the system could not have been absorbed since it shows up at D2. The event of the particle registering at D2 thus appears to retroactively cancel out the absorption by the opaque object that made this event possible in the first place.

The paradox resolves with the recognition that the interaction between the system and the opaque object was only *potential*. No actual interaction occurred. To eliminate the destructive interference at D2, the object encounters only a probability wave, not an actual particle. Laloë concludes that until the quantum system has been localized, one cannot attribute to it a single position or trajectory. Instead the correct description is in terms of the wave function of the whole system. Only when *both* probability waves of the system have arrived at a terminal point does the wave function collapse.

Far from retro-causality, the experiment demonstrates that potentiality occupies ongoing presence rather than an irreversible succession of instants. Finding the particle at D2 in no way indicates a temporally reversed elimination of the prior interaction with the opaque object that made the measurement at D2 possible. Instead this interaction, being purely potential, simply remains present until the experiment is completed. Only then does the wave function collapse, randomly, such that the particle is either lost to the opaque object or detected. In contrast to a potential event, which can remain present indefinitely, an instantaneous event yields to the past in the following instant.

The twofold time of quantum mechanics receives further corroboration by way of "indefinite causal order" (Wolchover 2021). As in the case of the interferometer experiment, a quantum system is sent through a beam splitter that separates it into two wave packets. One wave, A, transmits through the beam splitter while the other wave, B, reflects off of it. Each wave then encounters a pair of polarizing devices but in reverse order. Because wave B encounters the polarizers in the reverse order from wave A, the result differs for each wave. At this point the waves are rejoined by another beam splitter, and the reunified quantum system is then measured. The key finding is that both causal orders are implicit in the measurement outcome, meaning that no definitive order can be assigned to the encounters of the quantum system with the polarizers.

The basis of this outcome is that as long as the system is split between two probability waves, it occupies the fundamental time of indefinite presence. Only upon measurement does the system occupy the emergent time of a distinct moment, and only in this context is there causal order. Whereas the order by which the quantum system encounters the two polarizes is indefinite, the order of the experiment itself is definite: first the experiment is conducted and then it yields a result. Again we see that the time of wave mechanics is an indeterminate (ongoing) present, and the time of quantum measurement is a determinate (instantaneous) present.

Contrary to physical collapse models, wave collapse due to instantiation cannot be verified via measurement of a physical trace. Instead of an actual phenomenon, collapse is the *transition* to actuality. "If collapse really existed," as Igor Pikovski points out, "it would divide the world into different scales. Above a certain scale quantum mechanics would cease to be the correct theory" (Folger 2021, 43). Only the temporal divide between potential and actual is fundamental. The spatial divide on the basis of scale is an accident of the greater frequency of invasive interactions — that is, interactions that force a choice — at the macro scale.

4 COMPUTATION AND INFORMATION

The transition from potential to actual signifies the emergence of a distinct moment from the immeasurable temporal substrate. In the subjective context of human thought, potentiality is mere abstraction, a representation of our lack of knowledge. In the objective context of the probability wave, potentiality is intangible reality.

If the evolving wave function of mathematical analysis represents a physical process, this process is natural computation. Whereas configuration space in classical mechanics is an abstraction designed to aid human understanding, in quantum mechanics it signifies *computational space*, a virtual reality between the abstract and the actual. Only when a conflict between, say, a pair of atoms triggers the instantaneous reduction of the indeterminate dimensionality of computational space to the three dimensions of classical space is each atom a tangible entity with determinate properties. By default the atom is wave computation.

To solve the Schrödinger equation in a given circumstance, the wave function must include a term representing the external forces acting on the system (Gao 2017, 3). Without the Hamiltonian, human computation on the basis of the wave function would fall short of wave computation. The ability of neighboring systems to simulate conflict in computational space before it crystallizes in classical space means the three-dimensional world of the senses is implicit in high-dimensional computational space. The classical world is "rolled up" in the probability wave and unrolls with every instantiation.

Incorporation of the environment into wave computation is the basis of decoherence, whereby entanglement allows the coherence of a quantum system to leak into the environment, rendering the system *effectively* classical or "quasi-classical" (Ney and Albert 2013, 34). As Maximilian Schlosshauer points out, decoherence solves the problem of the nonobservability of interfering terms in superposition but not the more fundamental problem of why a measurement yields a single outcome as opposed to a superposition of outcomes (2007, 113, 331-33). As a subroutine of wave computation that removes interfering terms, decoherence cannot account for wave collapse. Though computationally anticipating the tangible interaction of system and environment, decoherence leaves out instantiation, i.e. *happening*.

Upon mutual instantiation a pair of atoms actualizes, thereby triggering a new round of wave computation with the atoms in a correlated state. So long as neither atom interacts with its environment, the persistence of this entangled state constitutes a memory of the interaction. This primary form of memory, which Bergson (1911, 20) signified by *duration*, is purely a function of ongoing presence. Irreversibility, the arrow of time, is limited to the subsidiary time of successive instantiations. Just as two atoms cannot occupy the same position in classical space, two instants cannot occupy the same position in classical time. By contrast, in the case of continuous presence, because no boundary distinguishes past from present, there is no past as such but only immediate presence and deep presence. Whereas the immediate present of a quantum system is expressed in its current set of superposed states, its deep present is the lingering influence of its initial state. This prolongation of the past constitutes the "working memory" of natural computation. Memory is built in to wave computation in accord with the Schrödinger law and is lost only with wave collapse. Likewise, whenever a pair of either-or inputs yields a single output, an electronic computer "forgets" (Landauer 1991, 24).

As Charles Bennett proved in 1973, in principle any classical computation is reversible in the sense that it need not generate entropy. In practice, of course, a small amount of energy is degraded, but even this can be eliminated by slowing the computational steps (Wheeler and Zurek 1983, 782). Whereas the ideal of lossless computation requires infinitely slow processing, in the wave-mechanical domain computation is already perfectly lossless and reversible. So long as wave computation is uninterrupted by external interaction, no entropy is generated. This is because time, fundamentally, is reversible and lossless presence. What is merely ideal limit for the classical is reality for the wave-mechanical.

By design a computer simulates mental computation. From the standpoint of physics, which excludes mentality, natural computation takes place only in a quantum system in its default state. Aside from the Schrödinger equation, no physical law specifies computation. The operations of a classical computer approximate wave-mechanical computation in exactly the sense that classical physics itself approximates the fundamental law represented by the Schrödinger equation.

Our sense of matter as enduring substance is an illusion generated by the cinematic effect of the extremely rapid recurrence of instantiation. Because a quantum system, prior to instantiation, consists of wave computation, the substance underlying recurrent materialization is recurrently updated *information*. The system begins as information, instantiates into matter, reverts to information, and so on. If the interaction of a measuring device and a quantum system generates a visible mark on a photographic plate, the information derived from this mark is merely a classical approximation of fundamental information.

This is contrary to the usual understanding. "Information," according to Rolf Landauer, "is inevitably tied to a physical representation. It can be engraved on stone tablets, denoted by a spin up or down, a charge present or absent, a hole punched in a card, or many other physical phenomena" (Whitaker 2006, 356). The red flag in Landauer's claim is "representation." The engraving on a tablet or the determinate spin of a measured electron cannot represent anything except in the mind of an observer. The necessity of a subjective observer reduces the informational content of a classical phenomenon to an approximation, as approximate as the phenomenon itself.

This applies equally to the contents of a classical computer. The key to computational modeling, according to Robert A Wilson (2005, 167), is that "causal transitions between physical states [are] represented as inferential transitions between computational states." Yet the computer itself cannot consist of anything other than physical states and the causal transitions between them. Only in the mind of the user does inference arise in place of causation. The informational content of a classical computer merely approximates the intrinsic information innate to both human cognition and wave computation.

5 MATTER AND MIND

A climatologist can derive information from tree rings, but this information has no tangible existence in the wood itself. Wood, after all, is comprised of molecules, not informacules. The information is exclusively the mental property of a knowledgeable observer. Likewise the brain contains no information, though a neurologist can derive information from a brain on the basis of scientific knowledge. As a thing in itself information belongs to either wave computation or thought and nowhere in between. If it belongs to wave computation, its projection results in matter. If it belongs to thought, the thinker may project it onto matter, such as words onto a page, but in this case the projection is subjective since the physical content of the page is merely patterns of ink that take on meaning only in accord with the interpretation of a reader.

If the mind and its intrinsically informational content is irreducible to any classical object, even a complex biological object, does this mean that mind and brain are distinct entities? Not if brain activity is simply the moment-to-moment materialization of mentality in the same sense that matter is the recurrent instantiation of wave computation. Indeed, the fact that wave computation involves both memory and information suggests a wave-mechanical basis of mentality. If so, the brain, rather than the basis of the mind, is merely its classical approximation. Given his refusal to consider the reality represented by the wave function, Bohr would have found no meaning in the idea of the mind as an adaptation of wave computation to macroscopic conditions. But the leap is less vertiginous for Heisenberg. If reality is potential as much as actual, why not mental as much as material? Perhaps the second clause is already contained in the first: to say that mentality is real is a roundabout way of saying that potentiality is real.

Bohr himself noted that an organism and its environment, like quantum system and measuring device, bind into an irreducible individual upon interaction, and he regarded this parallel between quantum mechanics and biology as the source of a generalized complementarity (Folse 1985, 186). The eye, for instance, in adapting to the nature of light, takes on a highly individualized structure irreducible to mechanics and chemistry (Bohr 1958, 7-8). If classical mechanics provides the "particle" aspect of the eye, then the "wave" aspect is its purpose in conjunction with the environment, that is, enabling the organism to see. In the case of the brain, we simply call its wave aspect "mind."

The distinction between wave computation and determinate particle boils down to continuous and discontinuous time. Invasive interaction drives the atom from its default state of continuous computation to a particle with a precise location at an instant, allowing it to serve as a building block of macroscopic matter. One such macroscopic system is a neuron, which in turn constitutes a building block of a brain. Since the mind and wave computation both serve as reservoirs of information, we may plausibly conjecture that the mind *is* wave computation associated not with an atom but with a network of neurons. If so, thought is a higher order wave computation.

Whereas first order wave computation is the basis of matter, second order wave computation is the basis of neural behavior. Thus thought depends on matter even as it serves as a causal agent in the activity of brain matter. The convoluted relationship of mind and matter is clarified according to the nature of time. The collapse of wave computation yields the *presentation* of matter. As matter is presentation, so mind is *re*-presentation, which entails not only the instant but the flux that conveys past into presence. What plays out in fundamental time as thinking – that is, organic wave computation – plays out in space-time as patterned neurotransmission.

In contrast to classical physics, which reduces brain activity to microscopic parts, human experience corresponds to macroscopic forms. The resulting mismatch, according to Henry Stapp (1993, 194, 201), prevents a physical approach to consciousness. Only by substituting classical with quantum analysis can we harmonize brain and mind, that is, recognize them as different sides of the same coin in the same sense that wave computation and particle are the two sides of the atom and, ultimately, ongoing and discontinuous presence are the two sides of time.

Quantum mechanics is revolutionary insofar as it replaces Newton's laws of motion with the Schrödinger law. That we can gain limited insight into brain activities on the basis of classical mechanics in no way renders the brain a classical organ. The law is wave-mechanical all the way up. Quantum mechanics specifies possible outcomes for systems of any size. The tendency of macroscopic systems to occupy a classical state is purely contingent, an accident of the jostling of atoms and the influence of electromagnetic fields. No physical law prohibits wave computation from reinstating at larger scales (Stapp 2017, 30, 36). Moreover, since the repetition of instantiation cannot efface the fundamental time of continuous presence, the capacity for wave computation to reinstate at higher levels always remains.

Even as the atoms comprising it undergo repeated wave collapse, a macroscopic system may still undergo wave computation in the right conditions. This is why, with great effort, scientists can induce macroscopic entanglement through precise control over conditions (Kotler, et al, 2021). To achieve the same end, nature seems to require nothing more than an energy source that enables multiple possible actions to take place at the macro scale. The brain, says Stapp (1993, 133), exemplifies this effect. The electrical activation or "action potential" of a neuron is probabilistic. Assuming each neuron has a 50% probability of activating at a given moment in a highly connected column of, say, 10,000 neurons, the quantum state of that column is a superposition of $2^{10,000}$ states, each of which corresponds to a unique set of synaptic connections over the entire column. The instantaneous collapse of superposition into a single pattern of neural firing constitutes both an irreducible macroscopic event in the brain and the crystallization of a distinct thought from the computational flux.

Because it entails kinetic energy and therefore movement and causation, matter is more than just particles instantiated at precise locations. Beyond the instantaneous departure from ongoing presence, causation is the macroscopic approximation of continuous time. As surely as one neuron activates another, the higher-order wave computation known as cognition depends on the higher-order temporal continuity known as causation.

If the mind is an evolved form of wave computation, which in turn is none other than the interiority of matter itself, then the unconscious mind is the interiority of the organism, that is, its reflexive responses to sensory inputs. Consciousness, by contrast, is holistic in the same sense as a measuring device and an atom bound into an irreducible whole at the instant of measurement. The question of how diverse sensory inputs are bound together into the perception of a distinct event – a.k.a. the binding problem – is strictly a mystery of consciousness. Whereas unconscious thought, according to psychologist Merlin Donald, yields only probabilities of what is being sensed, binding is "fast, clear, sharp" (2001, 181). The idea of the quantum leap enjoys popular appeal because each of us lives by the conscious leap.

6 EVOLUTION AND MEMORY

Though ongoing presence puts the "wave" in wave mechanics, time is incidental to classical mechanics. So long as change, as Bergson says, reduces to the movement of parts – and parts can always move back – "time does not bite into them." Temporal flux could be removed from the world without leaving a trace on classical physics (1911, 8-10). Not so with biology. Time is so embedded in lived experience that reductionists must conclude that consciousness conjures it up, projecting it onto the canvas of existence. Yet every aspect of life – evolution, development, memory, purpose, emotion, deliberation – implies the fundamentality of time.

Even before the onset of self-propagating species of life, the bite of time was evident in the self-organized chemical system far removed from environmental equilibrium. Sensitivity to its surroundings enables a nonequilibrium system to absorb and deploy energy, which in turn shapes the system and its chemical properties. Energy-driven matter-cycling systems adapt over time to energy sources because the better the fit, the more efficiently they feed. By way of illustration, whether the energy driver is breath or strumming or striking, musical instruments evolved so as to better absorb and channel it (England 2020, 127).

But natural energy drivers, as computer scientist Jeremy England points out, can be far more complex than the actions of musicians. Absorbing energy efficiently can require the chemical system to detect a hidden pattern in the energy driver, and figuring out a hard-to-discern pattern requires computation (2020, 190). For example, because a many-body problem cannot be plugged into an equation that yields a precise answer, physicists must resort to brute tabulation to solve it. The same applies to the olfactory seeking to identify an aroma. Sometimes the only way forward is to "sniff out" the pattern behind a complex array of inputs (2020, 207).

"When a collection of matter we have built with our own ingenuity behaves in a way that spits out an accurate prediction of a complex signal, we call that computation" (England 2020, 191). So when "a bunch of particles whose structure we did not design… is just as behaviorally successful with respect to the task of prediction," what do we call that? How can a system of particles organized by nothing more than energy flow engage in computation unless computation is already a property of nature?

Fill a bathtub with water and open the drain and you will soon discover a nonequilibrium system hovering over the drain. Because no physical law forces the water to form into a whirlpool – that is, because it self-organizes – the whirlpool appears spontaneously. But how can its formation be spontaneous when it happens every time without fail? So long as the bath is undisturbed, a whirlpool emerges sooner or later, shuttling water down the drain much faster than if it simply dropped in a straight line. From quantum mechanics we learn that nature computes probable outcomes of conflicts between physical systems. From nonequilibrium thermodynamics we learn that nature computes the most *efficient* outcome of a conflict between, say, where a body of water is currently located and where it must go to find its lowest energy state. Since it involves many atoms acting in concert, a self-organized system is holistic in exactly the sense of a multi-particle quantum system under the sway of a single probability wave. Either way, the computation is intangible, a function of the information from which matter repeatedly instantiates.

What applies to self-organized chemical systems applies equally to self-organized biological systems, i.e. organisms. Depending on the current requirements of the cell that houses it, an amino acid can spin, vibrate or become adhesive. The associations of amino acids known as proteins can self-organize into filaments or motors or enzymes (2020, 41, 202). Does this mean proteins and amino acids come equipped with miniature computers? Not if wave computation is at the very core of matter.

Like an electron forced to choose a location of impact on a rapidly approaching screen, a salmonella must periodically collapse its computation in favor of one outcome or another, in this case whether to feed in place or search for food elsewhere. Yet nowhere within the bacterium is there a brain-like site of decision-making. According to neuroscientists Ogi Ogas and Sai Gaddam, its "decision-making process is holistic," distributed across its "thinking elements" (2022, 34). Here we have not only intangible computation but entanglement of the disparate regions that materialize it moment to moment.

Ogas and Gaddam define perception as the act of distinguishing patterns in sensory inputs (2022, 97). With its network of near human-quality neurons, the roundworm perceives on the basis of many types of input, including temperature, salinity, moisture, odor, texture and vibration. Rather than react reflexively in the instant, it computes possible outcomes of actions before coming to a decision (2022, 89-93). Ogas and Gaddam are quick to point out, however, that brain activity in no way resembles the operations of a digital computer, which "requires precise, discrete instructions that must be followed sequentially. It requires 1s and 0s. A mind is almost the exact opposite of this. It consists of continuous and imprecise real-time activity happening everywhere all at once." Thought, say the authors, is fuzzy and holistic, an activity and not a thing (2022, 114). One could hardly hope for a better summation of wave computation in opposition to the artifice of computation electronically implemented by engineers.

That distinct particles routinely unite, through mutual interaction, under a single probability wave suggests that wave computation, though ordinarily inapplicable in the classical regime, can reinstate macroscopically by way of coordinated energy flow. If so, just as the probability wave depends on the time of ongoing presence, macroscopic wave computation depends on the classical approximation of fundamental time in the form of causal continuity. Whereas flowing presence underlies wave computation, continual *passage* underlies all macroscopic processes. But this only addresses the scaling up of wave computation, that is, its association with macroscopic material systems. How does it adapt to a living context? The leap from atom to boulder is hardly comparable to the leap from atom to chimpanzee.

The key to resolving this mystery lies, once again, in the nature of time, specifically the memory implicit in unbroken presence. Memory is indicated not just by the lack of boundary between present and past in continuous time, as in first-order memory, but the perpetuation of the past even beyond a temporal discontinuity. Like causation, second-order memory depends on the restoration of continuity beyond the recurrent instantiation of the atom. Whereas causation is ubiquitous in the classical domain, second-order memory must be teased out of its hiding places. One such place is the condensed matter system, which reveals emergent properties radically at odds with the properties of its components. Because a spin glass is randomly magnetized at room temperature, the magnetic poles of its atoms typically point in a jumble of directions. Only when cooled down does the system become magnetically coordinated. When the spin glass heats back up, however, its magnetic properties exhibit memory of its emergent coordinated state "as though an echo of the original treatment is stored in the configuration of the arrows" (England 2020, 193).

Second-order memory is a prerequisite for any nonequilibrium system that can detect a repeating pattern in an energy driver, as illustrated dramatically by an energy spike when the system is confronted by a change in the familiar pattern (2020, 195). Accurately predicting how a Taylor vortex regains internal equilibrium in response to a change in pressure, for example, requires knowledge of how it responded to previous changes. "In their cyclicity, they embody past modes of reaching equilibrium" (Schneider and Sagan 2005, 129).

Not every potentiality encoded in the wave function, according to Stapp, is eradicated by wave collapse. In each case one possibility survives, and this constitutes the "effective past," which Stapp defines as "the part of the past state that smoothly evolves into the immediate future" (2017, 58). But the effective past cannot be a smooth evolution reminiscent of the propagating probability wave given that even the surviving potentiality instantiates and therefore undergoes temporal discontinuity. Nonetheless, Stapp makes a useful point. In the case of a Taylor vortex, second order memory follows from the one possible outcome of a previous pressure change that became the actual outcome. Whereas first-order memory is limited to the flow of wave computation itself, second-order memory is a natural abstraction built up over time from a great number of outcomes of wave collapse. Whichever wave-mechanical potential typically survives collapse in a given context stands out in nature's memory from other potentials.

Time is not only presence and passage but the overlap we call memory. Each new instantiation cannot help, in the context of ineradicable presence, to modify the total sum-over-history of instantiations. Only the computation, not the underlying impulse of time, falters with invasive interaction. Far from arresting the extrusion of memory from ongoingness, instantiation shapes it, evolves it. Every instantiation constitutes a definite form, a way of being, and biases subsequent instantiations in favor of that form. Not just an interesting feature of life, memory is the means by which distinct forms of life persist, without which they could not evolve.

If evolution is a continuum from atomic to chemical to biological, most fundamentally what has evolved is wave computation – or, more precisely, the rules by which it plays out. The original impetus for evolution was the application of nature's computation to the task of exploiting environmental sources of energy. Just as identical quantum systems will compute identical probabilities in identical circumstances, essentially identical bacteria will respond to the same circumstance the same way. With the evolution of various bacterial species, wave computation branched into different lineages. Eukaryotic cells prompted further lineages, many of which were woven together with the emergence of multicellular organisms. Given that wave computation is always exploring "possibility space," in the words of Stuart Kauffman, the complexification of life was inevitable (Schneider and Sagan 2005, 91).

Darwin's interest in evolution was stimulated by the presence of aquatic organs in the embryos of terrestrial animals (1993, 598-99). Why should humans have four fin-like limbs and a swimbladder in the womb? Surely we would benefit from a streamlined embryogenesis that bypasses the cumbersome accoutrements of life in the sea. Though Darwin argued that adaptations made by adults of a given species are inherited by their descendants when they too reach adulthood, he noted that juvenile and especially embryonic forms remain largely unchanged by recent adaptations undertaken by adults (1993, 636). Darwin shared with Lamarck the belief that the inheritance of adaptations is essential to evolution. Since all organisms adapt to environmental changes or to unfamiliar environments, surely these adaptations play a role in the evolution of species. Darwin went so far as to say that the age-specific inheritance of adaptations "cannot be disputed" and must "stand or fall together with the whole theory of natural selection" (1993, 331).

To justify inheritance of adaptations in the context of materialist biology, Darwin proposed a complicated scheme called pangenesis whereby newly adapted organs slough off "gemmules" that travel to germ cells so as to be ferried into offspring. But the strict adherence to materialism makes no sense in light of wave mechanics and the recognition that matter is only the recurrent instantiation of information. Material configurations come and go, but information persists. To put it another way, the presence of a determinate object is fleeting, while the presence of information is ongoing. Like an atom, an organism repeatedly instantiates from an underlying body of (repeatedly updated) information. Each form exhibits stability through memory. The only fundamental difference is that the species to which the atom belongs is fixed, whereas the species to which the organism belongs is fluid.

7 THE MNEMIC MECHANISM

Quantum entanglement overturns the classical assumption that causality is strictly local. When an electron is measured spin up, we know that its entangled sibling 1000 light years away will measure spin down. Thus the local environment of the entangled sibling cannot possibly have determined its measured state. Locality is violated not only spatially but temporally. That an event is not necessarily conditioned by its immediate past opens the door to the influence of the deep past over the present, in this case all the way back to the moment the electrons were entangled.

Against the cosmic backdrop of continuous presence, recurrent elements of fleeting events cannot help but be abstracted into memory. The organism remembers because its stream of sensations takes place in the ongoing presence of mind. Yet nature's abstraction goes against the grain of the human intellect, which postulates an ideal realm beyond time in which to "place" abstract concepts such as justice, beauty, etc. Obscured by the imagined construct of the timeless ideal is the reality of living memory.

The concept of a natural form of memory was popular at the turn of the 20th century. German biologist Richard Semon, for instance, though agreeing with Darwin on the need for a material intermediary between the originator and the inheritor of an adaptation, maintained that this intermediary served merely as a stimulus for memory rather than a container (1921, 136-8). Prior to Semon's investigation, Ewald Hering had proposed linking heredity with habit and recollection (Semon 1921, 9). Like Hering, Semon saw no fundamental distinction between personal memory and the species-memory by which an embryo develops. Either way the effect is mnemic, that is, the incorporation of the abstracted past into the material present.

Semon was struck by Henry Orr's observation that a dormant memory can be resurrected in full with only a partial stimulus (1921, 10). This feature of memory is at odds with the mechanistic principle that output cannot exceed input (1921, 174). If a familiar scent can trigger the memory of not only a previous experience of that scent but the visual and auditory and emotional context, what is the source of the excess output? Perhaps the scent activates a particular neuron, which in turn activates a whole network of neurons, precisely the network that was activated upon the previous encounter. But this activation cannot be mechanically forced since any number of networks associated with that neuron might be stimulated. A given neuron can participate in numerous memories depending on which other neurons it activates in concert with. This is no different fundamentally from an electron having no definitive values of its properties except during interaction with its surroundings. The neuron has no specific "meaning" except in the context of the whole pattern of neural stimulation.

Likewise, a gene need not have a specific meaning if instead it triggers a species-wide memory when its activation in concert with other genes mimics prior activation. In this case, the cell that houses the newly activated genetic complex repeats the task it performed when the same set of genes previously activated. The "mechanism" is not mechanical but mnemic. The information is not encoded in the genes but is freed up from dormancy by the resemblance of current genetic activation with prior activation. Just as the mature organism responds to a given situation according to personal habit, the embryo responds to developmental cues according to habits long-ingrained in the species to which it belongs. Only the mnemic principle – on the basis of similarity between current and past conditions – suffices to ensure that the embryo follows the path laid down by its ancestors.

It was already well established in the early 20^{th} century that "large and arbitrary subtractions" can be made on the embryo without derailing its development (1921, 177). Semon asserted that the embryo's ability to reestablish its proper direction rests not on whatever material mechanisms remain within it after the subtraction but on the ever-present developmental end-point attained by numerous generations of previous similar embryos. This end-point or "attractor" operates not at all like a classical mechanism but – like wave computation – probabilistically. The embryo restores its ancestral path in the face of disturbances imposed during experimentation because this path is time-tested and proven. In contrast to the embryo, which has no reason to depart its deeply embedded path, a juvenile or mature organism might veer from its prior behavior if environmental conditions necessitate new adaptations.

Semon saw in the mnemic principle a conservative counterweight to incessant environmental change (1921, 14). Once introduced, an evolutionary adaptation is held in place under the weight of habit. Whereas novelty arises in the course of instantiations, stability is favored by the underlying continuity of past and present. The meaning of memory is that what instantiated before has a tendency to instantiate again.

In his discussion of the science of "evo devo," which combines the studies of evolution and development from the egg, biologist Sean B Carroll illustrates this tendency by clinging to a materialist interpretation of the organism despite acknowledging facts that falsify it. Chief among these facts is that the genes involved in embryogenesis are virtually identical in all animal species from insect to mammal (2005, 64). What has evolved over time is not developmental genes but the "switches" that regulate their expression (2005, 12). Yet the activity of this regulatory DNA is so complex that its operation can be analyzed only with combinatorial logic. "Because the combination of inputs determines the output of a switch, and the potential combinations of inputs increase exponentially with each additional input, the potential outputs of switches are virtually endless"

(2005, 124).

Carroll fails to recognize in this fact the end of genetic reductionism. Given the complexity of switches, physiological complexity cannot reduce to genetic simplicity. Far from an instruction manual for building an organism, the genome is part of the complexity that demands explanation. How can the operation of genetic switches, which is vastly more complex than a linear sequence of base pairs, be genetically encoded? Aside from divine intervention, there seems to be no explaining the operation of switches except according to the mnemic principle. Rather than mechanically forced to act a certain way, the switches of a given cell mimic genetic regulation in previous cells of the same type. Moreover, even if the switching on and off of genes did in fact proceed on a strictly mechanical basis, the end result would be a sack of proteins, not a finished form. According to the mnemic principle, not only is genetic switching regulated mnemically but so is every level of organic structure from protein on up. Whether in the case of a single cell or a multicellular organism, the living whole organizes its parts according to the memory inherent to its kind.

By repeatedly referring to "animal design" or "common design" or "modular design" as a product of evolution that unfolds in the course of development from the egg, Carroll (2005, 19-21, 28, 180-81) effectively treats evolution by natural selection as a materialist substitute for God, the "intelligent designer" of creationist myth. As long as biologists speak of living forms in terms of design – even a design worked out blindly through chance and natural selection – they cannot resolve the profound mystery of how a single cell, by way of a sequence of divisions, yields a highly complex creature. If the embryo, rather than adhering to a pre-existent design, need only follow the well-worn developmental steps of its ancestors, the "design" of the body is the body itself, that is, past iterations of the same species mnemically conveyed into the momentary present.

Whereas biologists materialize heredity as data encoded in the sequence of base pairs of DNA, and neuroscientists materialize thought as data encoded in patterns of neurotransmission, the chief lesson of quantum mechanics is that matter, far from housing information, is projected from it. As a quantum system instantiates from wave computation, a living system individuates from its species. Either way the informational whole is primary, the tangible system secondary. Even as individuals we all have the uncanny sense of wholeness, of a unitary self.

Whereas the body is spatially extended, the self is "within." This sense of wholeness, of an intangible yet active interiority, cannot be explained in a world according to classical mechanics.

The standard materialist model of memory, which concerns only personal memory in conjunction with the brain, leaves out temporal continuity. Memory researchers assume what Stephen Robbins calls the "classic metaphysic," according to which time is nothing more than a sequence of discrete instants. Because existence is limited to the current instant, the past equates to nonexistence. For this reason past experience must be stored in current neural configurations (2021, 24). Investigation of neural correlates of consciousness indicates that various aspects of an experience are distributed across the lobes of the cerebral cortex. On the basis of neural activity during subsequent recall of the experience, these distributed elements are believed to be indexed in the hippocampus, a region of the temporal lobe. Without this index we would have no way of bringing together the elements of a past experience into a coherent memory. Thus memory is thought to involve two kinds of information storage, the second of which, in the hippocampus, organizes the first to enable conscious access to our past (2021, 17-18).

Thus memory researchers go about studying the brain as if they were computer engineers. The setup researchers ascribe to the brain is exactly what is required for a computer to store and retrieve classical (approximate) information. But a computer, far from a self-organized system, is externally built so as to function in a precise and predictable way in accord with classical mechanics. The computer has no time of its own, no interiority, but is carried along on the classical timeline of successive instants. An organism has no need for information stored in its brain because it has a mind and therefore a deeper relationship to time. That which is mind over time is brain at an instant. The synaptic instantiation of an experience in no way prevents later re-instantiation. Rather than call up information *about* the experience, the reinstatement of the original synaptic pattern restores to the mind the experience itself, though of course without sensory accompaniment and therefore in ghostly form.

An organism is alive to the extent that ongoing presence animates it and the enduring past informs it. Otherwise the creature is a bundle of classical mechanisms, a computer-operated robot instead of a scaled-up and refined expression of wave computation.

In contrast to the approximation of information stored electronically in a computer, the information mnemically conveyed to a living organism is fundamental. This opens up the possibility that a particular type of protein, for instance, can serve as a *sign* indicating a beneficial direction in cellular activity. Thus the cell, apart from the forced causation of Newton, is also influenced by probabilistic semiotic causation, probabilistic insofar as the interpreter of the sign – the cell as a whole – can always choose a different behavior, perhaps as a result of conflicting signs. Causally efficacious "biosemiosis" makes sense given the symbolic semiosis that drives human culture. How are we as humans able to conduct our lives in accord with not only physical forces but symbols and interpretations if our own bodies are entirely subservient to blind mechanisms? How did conscious semiotic decision-making arise from strictly mechanistic biology except by miracle? If DNA is indeed a code and not merely a component of a chromosomal machine, the cell is the vegetative precursor to human interpretation (Gare 2022, 216, 228).

According to Bergson (1911b, 87), the past survives as the action-memory of habit and the representation-memory of recollection. Wave computation sets the stage for history and narrative when we find patterns over the course of recollected events. One story we love to tell is the triumph of the machine, an extension of the human ego, over nature. Theorists keep treating the brain itself like a machine because their brain states are informed by past brain states and therefore – barring conscious intervention – continue replicating the error.

8 CONSCIOUSNESS AND CULTURE

8.1 Background

Only in the context of a set of rules can wave computation yield potential outcomes. In quantum mechanics the rules are set. As determined by the Schrödinger equation, a given set of boundary conditions yields a given set of possibilities. This is known as the evolution of the wave function. Only by changing the boundary conditions such as the initial state of the system and the forces acting on it, can a different set of possibilities compute.

Biology is defined by a radically different meaning of evolution. Instead of meaning simply to unfold, the term now indicates the emergence of novelty. Not only does a computation unfold but the rules of computation transform. Like the US variant of football, evolving the rules yields not just a new match but a different kind of game and therefore a different set of possible outcomes. New rules by which wave computation plays out can expand the field of possibilities. This tendency is enormously amplified in human culture.

Like any self-organized system, the nervous system depends on "sniffing out" patterns of environmental activity. An octopus, for instance, solves problems with "endless pattern crunching" (Donald 2001, 158-59). Departure from the usual pattern triggers a spike in nervous activity. In humans, for example, infantile sucking intensifies when the infant notices a change. On the other hand, as a given stimulus is repeated, the response is automatized, that is, relegated to the unconscious. This is why boredom, says Donald, is essential to healthy development. In the quest for novelty, the infant churns through its field of experience "like some fantastic threshing machine, sorting, baling, and discarding impressions and ideas" (2001, 227-29). Though no different at first from the animal infant, in the following years the human metamorphoses via enculturation. We operate in two worlds simultaneously, only one of which is tangible. Human cognition requires "parsing a cultural landscape [and] discovering its hidden secrets" (2001, 255).

The dynamism of human culture both generates and reflects a much more expansive field of consciousness than is the case with octopi and other animals. Our focus is not just on the data of the senses and possible bodily responses but on memories and long term plans and how others perceive us, etc. Implicit in our parallel universe of symbols is awareness of mind. Animals have mentality but their focus is on the environment and the actions they take within it. Only in human consciousness does the focus become mind itself. We are in our thoughts as the squirrel is in the branches.

Even when taught sign language, apes never engage in conversation, as they lack the necessary depth of interior awareness. Donald attributes the rise of self-reflective consciousness to the attempt to refine the control of action (2001, 196-97). Instead of simply committing the act, our hominid ancestors began to reflect on it. Instead of focusing solely on the expected reward for the act, they considered the form of the act itself (2001, 272). They learned to rehearse, to review an act before performing it, and later to refine it on the basis of prior outcomes. In this way the seed of reflective thought already planted in the ape mind – as revealed by the art of deception – germinated in the hominid mind (2001, 130, 143). Once we have a sense of our own thoughts, we want to communicate them, first by gestures and then by words, which served to disambiguate the meanings of gestures. As Donald emphasizes, the driver in all this is consciousness. Language evolved – and continues to evolve – so as to placate our inner need to adequately characterize our observations and emotions. Our symbolic universe serves the drive for clarity (2001, 278-79, 291).

The task of a human is to make a narrative of one's own, a causal thread around which to self-define. Animal is defined at the level of species, the memory pool from which all members of that living form individuate both as moment-to-moment body and ongoing computation. To be herself, the animal must only follow the grooves laid down in organic computation space. For people the task of living is trickier. We define ourselves not only as projections of our kind but as conscious beings. Because self-existence for us is not merely bodily but mental, a heart is not only a pump, a mechanism of nature, but an opening into the very core of life – or a closing off and retreat into nihilism. A personality is a virtual being, intangible, a concatenation of memories and drives and meanings and *potentials*. What we call culture is the self-organized environment in which this virtual being takes on reality.

For the human infant, the gateway to the "parallel cultural landscape" is reciprocal eye contact. As the story of Helen Keller demonstrates, on its own the infant never thinks to engage in symbolic thought. We need a teacher to bring us into awareness of our interior world and to fill that world with symbols. Pedagogy originated as a technique for controlling a student's attention (2001, 255, 292). By synchronizing their thoughts, teacher and student not only form a conduit for the transmission of knowledge but set the stage for the student to bond with the larger culture, that is, to be incorporated into a "distributed cognitive process" (2001, 274). Donald refers to enculturation as cultural programming, which he likens to computer programming, with language playing the role of operating system (2001, 160). The impact on the brain is profound. Deep enculturation, unknown to other species, affects the way the brain is "wired" during development. Lurking always in the background, our culture subconsciously shapes our thought.

Cognitive communities have their own dynamics beyond the cognition of the individuals comprising them (2001, 212, 252).

One of the world's most successful cultural programs is marriage. When young people are in love, they are encouraged to commit to each other for life. If the attraction between them proves transient, however, marriage might not be in their best interests. What makes the institution of marriage so widespread and enduring is that it benefits society by promoting stability in the home environment of children, which in turn promotes their lifelong emotional well-being. Despite its conflict with our need for flexibility and freedom, the marriage program is a reasonable way of balancing the needs of adults and children.

The pathology of the marriage program is its patriarchal component, which equates women with property. Marriage, by this inhuman logic, is merely a change of ownership from father to husband. Given that women, not men, give birth and act as primary caregiver for the first several years of life, the social diminishment of women cannot help but negatively impact children, undermining the stabilizing benefit of marriage. Human reason has gradually prevailed over the mindless perpetuation of the patriarchal program, reconfiguring marriage into a union of equals, either of whom can opt out if conditions become intolerable. Perhaps in response to this triumph of reason over pathological cultural programming, the age-old practice of abortion, which in human history has never been morally contested, suddenly came up against intense opposition in the 20^{th} century. Given that a fetus is self-evidently not a human being – that is, has not even begun to develop reflective consciousness – far from protecting actual human life the basis of anti-abortionism seems to be the re-subordination of women. Where abortion is banned even to save the life of the mother, it becomes homicidal, a mockery of the "pro-life" delusion of those who unknowingly serve the patriarchy program.

If mind instantiates as neural activity much as wave computation instantiates as matter, then human consciousness instantiates as artifacts, the leavings of culture. And just as instantiation triggers a new starting point for wave computation – and neural activity conditions what is thinkable – culture shapes consciousness. Though our culturally-mediated symbolic universe has enabled us to develop tools that enhance quality of life, by stepping into a world made of symbols we can easily disconnect from reality. Buoyed on the currents of natural memory, our cultural programming readily takes on a life of its own, perpetuating misunderstandings and blocking our individual capacity for reason.

8.2 War and Capitalism

Archeological records disclose no trace of large-scale violence prior to a massacre in what is now the Sudan some 13,000 years ago. Signs of warfare go back only about 12,000 years (Ehrenreich 1997, 117). As far as we know, war is a relatively recent development and therefore a cultural product, not an expression of human nature. This explains why training soldiers to kill requires intense indoctrination and drilling, and even then many soldiers have great difficulty firing directly at an enemy soldier (1997, 10). We know that tools of war originated as tools of hunting (1997, 118), but what possibly could have pushed late Paleolithic people to engage in mass murder? Economic need cannot explain it since there would have been plenty of earlier periods of privation that never led to war. Could it have been a simple matter of underemployed hunters looking for work? This may indeed have been a factor, but it cannot explain how people en masse could normalize and even glorify the systematic killing of our own kind.

Because it entails attacking and killing our own kind, Barbara Ehrenreich likens war to an autoimmune disease, wherein the immune system fails to distinguish self from other (1997, 95-96). Surely a pathology this disturbing originated in trauma. The late theorist and author identifies the trauma in question as our long history as a prey species (1997, 22, 47). Not only humans but our hominid predecessors were routinely attacked and killed by predators such as lions, tigers, bears, wolves, etc (1997, 40, 52). Though predation of humans has never abated completely, rarely do people today end up as cat food (1997, 42). We not only escaped the clutches of powerful animal predators but eventually became the world's foremost predator ourselves, at the top of every food chain on land and sea. This transition, says Ehrenreich, is the central story of the human narrative (1997, 77, 82-83). No matter how many times we compulsively recapitulate our transformation from victim to hero – mostly through popular stories of the victorious underdog – the well of anxiety replenishes from the deep memory of our primordial weakness. Like a swimmer swept out to sea, consciousness is easily overwhelmed by the unconscious.

According to ethologist Konrad Lorenz, militant enthusiasm evolved from the communal defense response of our prehuman ancestors. When a predator entered a human encampment, the most effective response – far better than simply scattering – was to mob together and raise a ruckus, hurling stones at the beast and taunting it (1997, 77, 81). When successful it served as a bonding experience for the tribe. But even when it failed, only one person died. Lions kill for food, not sadistic pleasure. Once the lion secures its kill, the rest of the encampment is safe – at least for the time being. The one who dies, says Ehrenreich, has effectively been sacrificed for the preservation of the community (1997, 59).

The end of the last Ice Age, circa 12,000 years ago, is the most recent era of intensive global warming. Like the current era, it took a toll on ecosystems. Around the world populations of grazing animals plummeted, leading inexorably to a similar decline in the populations of predators (1997, 118-20). The rational response would have been to breathe a sigh of relief that the dreaded enemy was no longer a significant threat. But the human mind, like any mind, is potentiality informed by living memory. Given the terror inspired by the predator beast and the suddenness and viciousness of its attack, every killing would have been folded into the shared memory of humankind. For thousands of centuries, predation anxiety was expelled by a human sacrifice. A cycle this deeply ingrained cannot be expiated overnight.

Though wars of conquest are easily rationalized according to self-interest, ritual human sacrifice seems to defy all reason. How could such a brutal and self-defeating practice ever have arisen? Yet it crops up in every region of the ancient world (1997, 62-65). Even Stonehenge has victims of sacrifice buried beneath it.

If the sense of overwhelming power associated with religious awe stems from an experience common to tribal people, it was surely the terror inspired by face to face contact with a hungry predator. Is it any wonder then that God, in the beginning, was a predator beast? Not just Jehovah and Zeus but goddesses like Cybele, Sekmet, Kali, Inanna, Astarte and Artemis all required blood sacrifices (1997, 73, 97). Many societies have worshipped predators directly, without even the symbolic intermediary of a deity (1997, 74). When the lion disappeared from the savanna, it simply relocated to our minds. By sacrificing one of their own to a hungry deity, post-Ice Age peoples triggered the mnemic mechanism, achieving the same release from unbearable anxiety that their forerunners had achieved naturally. Ehrenreich's conjecture makes sense of an otherwise senseless practice.

Is it only coincidence that priests carried out ritual sacrifices and, in later generations, sanctified battlefields? Sacrificing a member of one's own tribe is self-defeating. War, on the other hand, has a built-in means of self-perpetuation. Every time a tribe seizes a victim, the neighboring tribe can overcome grief through rage and counterattack. On and on it goes, each side recapitulating with every attack the human transition from prey to predator (1997, 139). The monster is always the other: Saddam, Kadhafi, Putin, etc. Never do we see the predator in the mirror.

Though hatred of the enemy figures prominently in war, of equal importance is love of community and the desire to sacrifice for it. Historically the point of going to war, says Ehrenreich, was not so much to slaughter the enemy as to die for a great cause. War has the power to sweep up whole nations into ecstatic frenzy, well illustrated by mobs of patriots in European capitals in 1914. The tradition of honoring the "unknown soldier" reflects the loss of individual identity as citizens merge into the polity (1997, 14-18). War is a triumph of cultural programming over individual intelligence. So long as it stirs up the ancient fear and washes it away with a reminder of our newfound power, war will be rationalized despite its obvious evil. The enslavement of conquered peoples, the class divide between warriors and peasants, the demotion of women to the status of prey, none of it matters when conscious thought has been hijacked by the most powerful program ever inserted into the human software.

Vladimir Putin's 2022 attack on Ukraine is a mirror image of Bill Clinton's 1999 attack on Yugoslavia. In each case a powerful country violated international law by dislodging a contested region from a weaker country, Kosovo in the case of Yugoslavia and Donbas in the case of Ukraine. Yet Westerners revile only Putin, not Clinton. To add to the irony, it was Clinton who began the eastward march of the North Atlantic Treaty Organization, the US-backed military alliance that sponsored illegal attacks on not only Yugoslavia but Afghanistan and Libya. Given its history of aggression, NATO's militarization of Ukraine predictably set off alarms in Russia. Putin amassed troops at the border and requested that the Ukrainian government pledge neutrality and stop the killing of Russian-speaking residents of the Donbas. The response from Kiev was a 20-fold increase in shelling of the Donbas (OSCE 2022). By claiming that Putin's subsequent invasion was unprovoked, Western governments and media effectively removed it from the stream of time, rendering it incomprehensible except as an imperialist land grab. If so, however, why did Putin wait until NATO had turned Ukraine into a hostile and well-armed power at Russia's doorstep? Why not invade years earlier when doing so would have been easy? But asking questions like these is to engage in the act of reasoning, precisely what is forbidden by the war mentality and cultural programming generally.

Deranged as it is, war at least has heart. The warrior is moved by concerns beyond his personal well-being. What counts is not self-interest but the needs of the tribe, i.e. the nation, the irreducible whole that lives on through the blood sacrifice of its most courageous citizens. Capitalism, by contrast, is cold and calculating. No one ever willingly sacrificed everything for a corporation. For the capitalist a nation is a convenience, a legal framework safeguarding the rule of the market. When the corporation outgrows the nation, it globalizes and takes cover under an international legal framework. Unlike an irreducible nation, a market is nothing but the sum total of buyers and sellers comprising it (1997, 195-97).

If war is the fulcrum on which the human story turns, capitalism, says Luciano Pellicani, is "the most fateful force in our modern life." Far from merely an appendage of the market, capitalism is a "self-regulated system of markets" animated not by goods but the act of acquiring them. Whereas war refashions the human mind around the logic of the noble beast, capitalism removes traditional fetters on the self-interested ego, setting it loose upon the world to prey on the less privileged. With its "self-propelling" will to acquire, capitalism undergoes continual expansion and transformation in its "frantic search for new fields of action, i.e. new markets" (1994, 7-8).

Citing Marx, Pellicani explains how capitalism warps the traditional market. Instead of bringing a product to market and using the money earned from its sale to buy other necessities, the capitalist starts with money and invests it in both the machinery of production and the labor to operate it so as to produce a commodity, which he then sells at a profit. In place of the producer, money itself is the originator of profit. Hence money, like an organism, reproduces, each passage in its life-cycle augmenting the wealth of the capitalist at the expense of the producer. The dazzling wealth generated by capitalism casts a long shadow of poverty and insecurity. Insofar as it frees markets from traditional restraints and ethical norms such as the "just price," capitalism is a law unto itself, a "spontaneous calculator" that self-organizes from the matrix of human needs and desires (1994, 9-12).

Before computers were machines they were capitalists. Devoid of the passions that inspire religious, military or political leaders, capitalists embrace the impersonal laws of exchange, extracting data so as to predict the effects of various possible investments. The fruit of their calculations, in Pellicani's words, is "an economic organism" that lives for a hypothetical demand in the form of potential customers. Merchants and lenders stimulate demand, which in turn stimulates production. The circuit is completed when profits are reinvested, keeping "the machine of capitalism in perpetual expansion." Originating in northern Italian city states as an association of capitalists, the corporation embodies the capitalist circuit long after the deaths of its founders. In the corporation capitalism offers a new and improved beast, a pure expression of wave computation unburdened by human concerns such as love or self-sacrifice (1994, 153-60).

Just as war propagates through the cycle of violence and retribution, capitalism self-perpetuates by extracting wealth from laborers and thereby keeping them needy and desperate enough to continue accepting work at exploitative wages. This downward pressure on working people is enormously exacerbated by subjecting credit and debt to the logic of the market. The interest rate on a loan charged by a bank is whatever the market will bear, well beyond the administrative cost to the bank. No need to earn wealth when the money loaned by the bank reproduces of its own accord. As Adrian Kuzminski puts it, "the practice of largely unregulated private credit at unearned rates of interest has been normalized to the point of being almost entirely taken for granted." We accept "the concentration of wealth in the hands of creditors at the expense of debtors… as if it was a natural evolution of social practices" (2022).

In reality, private credit emerged on a large scale only with the emergence of credit based on potential wealth in lieu of tangible wealth. In the late 17th century the British parliament established the Bank of England as a consortium of private creditors who assumed the national debt and issued bonds to be repaid with interest by the state on the basis of tax revenues. "For the first time ever," writes Kuzminski, "the taxing power of the state was used as a reserve fund for a national debt held by private investors for their profit" (2022). The resulting expansion of credit, the repayment of which was guaranteed by nothing but the expectation of future revenues, funded war abroad and industrialization at home. The British Empire – and beyond it the entire modern era of industry and high technology – was triggered by nothing more than a few bankers and politicians plunging into a heretofore unexplored region of wave computation.

By the late 19th century the American populist movement took shape in the struggle against the monopoly power of private banks over credit and debt. The banks won that struggle and today Americans are swamped in debt, much of it brought on by student loans and exorbitant medical bills. Alongside the wage system, the debt system generates widespread financial insecurity. Only the overall expansion of wealth counters the downward suction, allowing most people to stay out, at least temporarily, from the pit of poverty and desperation. Like the Bank of England, the world economy stays afloat on the potential of ever greater wealth.

But endless expansion of production and consumption comes at a price. Just as war threatens universal destruction via nuclear weapons, capitalism does the same by way of ecological collapse. In both cases the madness has come about through the substitution of conscious reasoning with cultural programming. The American and Soviet governments allowed thermonuclear weapons to proliferate into the thousands because that was the next step in the logic of war, a logic that was normalized through millennia of conditioning. The hurricane of economic activity unleashed by capitalism relentlessly impinges upon and even obliterates vibrant ecosystems because pursuing self-enrichment without regard to sustainability has been normalized through centuries of conditioning. As long as the world is ruled by blind computation in place of conscious reflection, we risk self-annihilation. The only question is which predator beast, Moloch or Mammon, sinks its teeth into us first.

8.3 Entropy and Economy

Schneider and Sagan refer to self-organized systems as "gradient-organized" because the energy that animates them is derived from breaking down environmental gradients (2005, 85). A whirlpool, for instance, exploits a pressure gradient in a liquid. Opening the drain of a bath creates a gap between where the water is currently located and where it "wants" to go on the basis of gravity.

The whirlpool is sculpted by its pattern of energy flow, which happens to be the most efficient possible pattern for closing the gap. As soon as the drain is closed, the whirlpool vanishes – that is, reverts from actual to potential – since it no longer serves to reduce a gradient.

Money plays the same role in the human world that energy plays in the natural world. Due to the symbolic value we attach to it on the basis of cultural programming, money organizes the flow of matter, whether raw materials or finished goods. If money stops pouring in, a business either dies or finds a new market. Even better is to stop relying on production altogether and make money via arbitrage, which exploits the pricing gradient between different locations. Either way profitable investment tends to heighten the flow of goods through increasingly interconnected systems (Schneider and Sagan 2005, 276-79). Though greater complexity and connectivity facilitate greater wealth, the failure of any component can produce system-wide collapse (2005, 205). Whether biological or economic, complexity offers rewards but at an ever-present invisible cost.

Energy, according to the second law of thermodynamics, tends to dissipate as waste heat, a process known as entropy. Because a system is distinguished from its surroundings only insofar as it channels energy, the dissipation of energy tends to efface the distinction between system and environment. Dissipative systems, including organisms, resist the entropic slide to equilibrium, maintaining their identity apart from the environment by balancing imported energy with the efficient export of waste. Just as an organism must import energy and export entropy, a manufacturer must ensure not only the influx of money but the outflow of waste. Because energy is degraded as it powers the metabolic cycles of an organism, it becomes a burden unless the organism can export it. Dissipation of low-grade energy takes the form of heat as well as liquid and solid waste – in the case of animals – and pollution in the case of manufacturers. Whereas an ecosystem recycles waste, modern economies mostly externalize it, such as excess nitrogen from fertilized farmland into rivers and excess carbon dioxide from power plants into the atmosphere and ocean.

As reflected in chronic low-level inflation, the decay of the built environment is an easily overlooked source of entropy. Death for an animal is nourishment for the earth and, by extension, other animals. A product of human technology, on the other hand, is never alive in the first place and therefore begins to decay at the moment its fabrication is completed. Unlike self-healing organs and tissues, products of manufacture need external maintenance which, over time, generates a drag on the economy. With its numerous buildings and vehicles and infrastructure and the bureaucracy required to manage it all, a city is haunted by its own prior development. Today's global economy, with its vast infrastructure of transport and security, only globalizes the entropic weight. The reflexive response is further growth, amplifying the problem in the long term.

Rising cost of maintenance combined with complex interconnection is the perfect recipe for social collapse and the primary reason – along with overuse of resources – for the dismal repetition of such collapses in history, most notably once-powerful empires (Greer 2005, 8-9). Typical in this regard is the collapse in the West of the Roman Empire. Every conquest by which the empire built up generated a huge infusion of wealth followed by centuries of costly administration and defense. The resulting tax burden fell largely on the backs of smallholder peasants. To meet their obligation after a bad harvest, they sometimes had to borrow the money. Failure to make loan payments meant foreclosure and tenancy on land they formerly owned. Yet they were still taxed. Unable to borrow, another bad harvest could mean imprisonment, their children sold to slavery and their land abandoned. By consuming its primary source of capital in this way, the empire hollowed out from its core and lost its ability and even its will to resist "barbarian" incursion (Tainter 1988, 146-50). As Gibbon put it, "the causes of destruction multiplied with the extent of conquest" until "the stupendous fabric yielded to the pressure of its own weight" (2000, 435).

To step back from the precipice, to avoid the fate of our predecessors, we must free ourselves of large-scale centralized systems of energy and resource extraction, reducing complexity and interdependence as much as possible in favor of local self-sufficiency. Yet countries the world over, instead of scaling back and minimizing energy flow and waste production, follow the US lead by pumping up economic activity to the maximum and continuing to lavishly subsidize fossil fuel extraction.

Ehrenreich points out that the passions whipped up by war, such as courage and solidarity and self-sacrifice, can also be harnessed in the struggle against it (1997, 240). As the Occupy Wall Street movement briefly demonstrated, a gradient – in this case between the actual world and the one we want and desperately need – can energize large numbers of people to agitate against the concentrated power that puts its own perpetuation ahead of ecology, including human ecology. The problem in 2011 was the absence of a coherent demand, a unifying vision to bind the occupiers into a force for systemic change.

If a single policy change could reverse the mad rush to self-destruction, it might just be Kuzminski's proposal to replace private banking with a public system that would lend money at 1% interest. Such a system would break the state-chartered monopoly power of private banks, on the model of the Bank of England, to set interest rates. But then why not 0%? After all, along with rent and the systematic underpayment of workers, interest-bearing loans siphon wealth from the producing class to the owning class. The problem, again, is entropy. Because of the silent and little noticed drag on the economy, we have an obligation to earn not only the money that pays for our consumption but a little extra so as to pay for the depletion of resources and depreciation of durables that occurs in the course of our consumption. Like 19th century populist Edward Kellogg, Kuzminski estimates that the repayment of loans at 1% interest suffices to maintain the minimal material basis of society, that is, a steady-state economy. A rate of interest higher than 1% is essentially extortion on the part of creditors of what rightfully belongs to borrowers, that is, the people whose labor produces actual wealth. Even worse, it threatens to undermine society as a whole.

Any rate above 1% compels the appropriation of resources beyond that of a steady state economy. It forces any economy to depart from a steady state and enter a growth path, no matter what, even at the cost of depleting resources. A 1% rate, on the other hand, does not preclude growth any more than it commands it. Any growth which loans at 1% are able to stimulate will be entirely in response to the conditions and opportunities available, and not be forced beyond their means by the external compulsion of satisfying a higher rate of interest (2022).

Thus we can choose to grow when conditions are right, but we can also respect nature's limits and refrain from growth. The point is that the decision to grow is a matter of conscious reflection on current conditions rather than the automatized imperative of unhinged wave computation, which banks everything on a bright future that one day will no longer exist.

So long as wealth is vacuumed up in the forms of rent, exploitation and interest, the economy must continue expanding just to maintain current living standards. By removing usurious interest from the equation, many more people are able to own not only a home but a family business and thereby avoid not only rent but exploitative wages. The result is a strengthening of the middle class, not in the European sense of a bourgeoisie between peasantry and nobility but in the American sense of the bulwark of a healthy society of independent producers.

In the end the Occupy movement offered nothing more than denunciations of the "one percent," the elite in whom the wealth and power of the nation are unjustly concentrated. By placing a very different spin on that term, Kuzminski offers the hope of a constructive movement that unites left and right to restore sanity and cohesion to a fractured society.

9 CONCLUSION

Modern science, as Pellicani points out, arose just as capitalism was emerging as the dominant form of social organization. As with science, success in the market comes through respect of objective laws. Because the market necessitates gathering data so as to calculate and make predictions, capitalism engenders quantitative thought on the basis of impersonal laws. In the exacting world of the market, superstition has no place and nature is strictly objective (1994, 171-76). Science likewise adopts a materialist orientation, though the meaning of the term differs. Whereas capitalism is materialistic in the sense of valuing material acquisition, for science matter is treated as fundamental reality, the substance underlying sensorial objects. Yet the laws by which atoms behave are by no means themselves composed of atoms. Aping the dualist ideology of capitalism, science incoherently combines materialism with the quest for timeless and intangible law.

The trouble with materialism is the impossibility of explaining the regular behavior of material systems from atoms to galaxies without invoking immaterial principles. The problem with immutable law is that experience is inherently temporal. As it happens, the fundamental law of nature – as represented by the Schrödinger equation – demands ongoing presence, the polar opposite of timelessness as ideal limit. Eternity dissolves into flux.

If our starting point is the objective world of the senses, we cannot take the leap to mind and idea. If we start with timeless mathematical principles as the underlying order of nature, we cannot account for novelty and narrative. Though quantum mechanics demonstrates that the continually changing sensorial world emerges from fundamental law, this law specifies the *ongoing* computation of outcomes of potential events. Because continuous presence never stops spilling over into fleeting presents, history is implicit in the fundamental order.

Simply by starting with time we get both matter and mind. Flowing presence externalizes into space-time and evolves into consciousness. Out of wave computation arises not only the phenomenal world via rapidly recurring instantiation but the contemplation of that world via the expansion and complexification of the rules by which wave computation plays out. Continuous presence yields time in the physical world, life in the chemical world and introspection in the human world.

In reflective consciousness the world is remade in symbols, and our subservience to those symbols can lead us to conflate disorders of our own creation, such as war and capitalism, with the natural order itself. No matter how technologically advanced, when a society becomes sufficiently disordered, nature is apt to extinguish it. To avoid this outcome, we must resist cultural programming and place ourselves fully in the ongoing reality.

In opposition to Bergson, Gaston Bachelard proclaimed the instant the whole of time and equated the "present instant" with reality. Bachelard held that Bergson's duration – with its unseemly bleeding of past into presence – is incompatible with novelty. If Bergson was right about time, claimed Bachelard, nothing truly new could ever take place (2000, 64, 80). What he overlooked was ongoingness, the continuous prying open of the future. Like memory, novelty is built in to time, and only its absence requires explanation. That the present is informed by the past in no way precludes spontaneity and creativity. Bachelard, in short, was an absolutist: novelty is either an absolute break with the past or an illusion. Where Bergson simply perceived – gradations and all – Bachelard mistook abstract absolutes for reality.

Against a backdrop of systemic injustice, the global environmental crisis demands radical change. For the socialist left, this means seizing political power to remake the economy in the interests of social and natural ecology, imposing from above a wholly new way of living. Yet the prospect of such a destabilizing seismic shift generates fear more than hope even among people who would benefit most from the change. An absolute break with the capitalist past in a country made rich by capitalism is unthinkable. Even a narrowly-defined policy change like public lending at 1% interest, which poses no threat whatever to market exchange, is beyond the bounds of acceptable discourse for the ruling global elite and its affluent servant class.

If legislating the new society into existence is chimerical, the only way forward is to recapitulate, in a socialist context, the capitalist-scientific creation of the modern world. True revolution begins with *evolution*. The bourgeoisie had been building a new economy for centuries – all the way back to the late medieval city states of northern Italy – before they were overturning monarchies. In the end, taking history in a new direction means cultivating, from the ground up, an egalitarian economy. If the bourgeoisie could self-organize in the act of breaking down the gradient between what people want and what they have, a new class of people – or rather a class-transcending people – can do the same in the midst of an entrenched capitalist order sinking ever faster under the weight of its prior overdevelopment.

Bergson was right. True novelty arises organically, unforced, like a seedling sending up a shoot from the living depths.

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