Answering Descartes: Beyond Turing

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Foreword

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Introduction

The first half of the 20th Century was filled with a stunning group of scientists, Einstein, Bohr, von Neumann and others. Alan Turing ranks near the top of this group. I am honored to write in this Centennial Volume commemorating his work. How much do we owe one mind? His was a pivotal role in cracking the Nazi war code that profoundly aided the defeat of Nazism. His invention of the Turing machine has revolutionized modern society, from universal Turing machines to all digital computers and the IT revolution. His model of morphogenesis, the first example of a "dissipative structure", to use Prigogine's phrase for it, is one I have myself used as a developmental biologist.

I rightly praise Turing, but seek in this chapter to go beyond him. The core issue is the human mind. Two lines of thought, one stemming from Turing himself, the other from none other than Bertrand Russell, have led to the dominant view that the human mind arises as some kind of vast network of logic gates, or classical physics "consciousness neurons", to use F. Crick's phrase in The Astonishing Hypothesis (1), connected in the 10 to the 11th neurons of the human brain.

I think this view could be right, but is more likely to be wrong. My aim in this chapter is to sketch the lines of thought that lead to the standard view in computer science and much of neurobiology, note some of the philosophic claims for and doubts about the claim, but most importantly I wish to explore the emerging behavior of open quantum systems, their new physics, and, centrally, our capacity to construct what I will call non-algorithmic , non-determinate yet non-random Trans-Turing Systems. As we shall see, Trans-Turing systems are not determinate, for they inherit the indeterminism of their open quantum system aspects, yet non-random due to their classical aspects. They are new to us, and may move us decisively beyond the beauty but limitations of Turing's justly famous, but purely classical physics, machine.

Beyond the above, I shall make one truly radical proposal that I believe grows out of Richard Feynman's famous "sum over all possible histories" formulation of quantum mechanics,(2). This formulation is fully accepted as an equivalent formulation of quantum mechanics. I will show that Feynman's formulation evades Aristotle's Law of the Excluded Middle, while classical physics and, a fortiori, algorithmic discrete state, time, classical physics, Turing machines, obey the Law of the Excluded Middle. Following philosopher C.S. Pierce, who pointed out that "Possibles" evade the Law of the Excluded Middle, while Actuals and Probable obey that Law,(3), and Alfred North Whitehead,(4), I shall propose for our consideration a new dualism, Res potentia and Res extensa, the realms of the ontologically real Possible and ontologically real Actual, linked, hence truly united, by quantum measurement. In contrast, the dualism of Descartes, Res cogitans, thinking stuff, and Res extensa, his mechanistic world philosophy, have never been united. I believe Res potentia may be a consistent and new interpretation of "closed" quantum systems prior to measurement. These ideas and other much less radical ones resting on open quantum systems lead to new and testable hypotheses in molecular, cellular, and neurobiology, and, hopefully, a new line of ideas in the philosophy of mind including proposals about: how mind acts acausally on brain, an ontologically responsible free will, what consciousness IS, the experimentally testable loci of qualia as associated with quantum measurement itself, the irreducibility of both qualia and quantum measurement, the unity of consciousness, i.e. the "qualia binding problem" and its cognate "frame problem" in computer science. From these, technological advances in numbers of directions may flow.

Mind as Machine

As noted, there are two strands, from Turing and the Turing machine, and from Bertrand Russell, that both lead to the view of the mind as a classical physics "computing machine".

The strand from Turing is well known. It begins with the Turing machine, the very definition of algorithmic behavior. To recall, a Turing machine consists, in general, of an infinite tape divided into squares. On each square one of a finite number of more than one symbol, say "0" and "1", is written. A reading head begins poised over one square. The head contains two sets of rules. The first rule prescribes the following actions: If situated over a tape square with a given symbol written on it, the head will stay where it is, move one step to the left or right, erase the symbol on the square below it, and write a symbol from the defined alphabet of discretely different symbols on that square. The second rule specifies that under the above conditions, the reading head will change from one of a finite number of discrete internal states to some internal state. Thereafter, the system iterates. There is, in addition the crucial "halting state".

Turing showed that any recursive computation that could be carried out could be carried out by a universal Turing machine. From this followed wonderful theorems about the formal undecidability of the "Halting problem", the demonstration that most irrational numbers were not computable, and other remarkable advances.

The feature of the Turing machine I wish to emphasize is that it is *absolutely definite* or *determinate*. Given the symbols written on the tape, and rules in the reading head, its behavior at each step is fully determined. This determined behavior is essential to the algorithmic character of the Turing machine. Because it is determinate, the Turing machine is bound by classical physics. However, Turing machines are discrete state and discrete time systems, while classical physics more generally is based on continuous variables and continuous time and is also deterministic, and can, since Poincare', exhibit deterministic chaos.

Computer scientists often distinguish between algorithms that may halt with an answer, and those that are "processes", such as Holland's Genetic Algorithm (5), which just continues or halts at some defined success criterion.

Turing, in the Turing Test, or "Imitation Game" (6), soon turned to the question of whether the human mind was itself a Turing machine. He thought, after careful consideration, that the answer was "Yes". He did, however, retain doubts, partially reflected in his use of humans, not algorithms, as the judges in the Turing Test. Turing scholars rightly admire his capacity to doubt himself.

Russell and Onwards to Mind as Machine

At the turn of the 20th Century, Bertrand Russell, having just published with Whitehead the Principia Mathematica, turned to the problem of maximally reliable knowledge of the "external world". We could be wrong, he reasoned, that there was a chair in the room. But we could hardly be wrong that "We seemed to be seeing a chair". That is, statements about our experiences, say visual, were less corrigible, or error-prone, than our statements about the external world. Russell and his contemporaries, including the young Ludwig Wittgenstein, hoped to build up knowledge of the external world from experience itself.

Pause and look at the room or world around you. You experience a "whole" visual field called in neuroscience, the "Unity of Consciousness". This unity will be central to my interests. However, Russell threw away the Unity of Consciousness in his very first philosophic move. He invented, whole cloth, "Sense Data", such as "Red here" or the musical note "A flat now" (7). That is, Russell shattered the unity of consciousness into bits, soon to be related to computational "bits".

Russell's next step was to invent "Sense data statements". "It is true for Kauffman that 'A flat now'",(7).

Why did Russell make this move? Because his Principia hoped to construct the entire mathematical world from first order predicate calculus. Then the hope was that the statement, "There is a chair in the room", could be translated into a *logically equivalent statement* comprised of a finite list of true or false sense data statements and quantifiers such as "There Exists", and "For All". If the move worked, knowledge of the external world would be set on a firm foundation.

The discussion took perhaps 40 years, but the move, culminating in the Tractatus Logico-Philosophicus by Wittgenstein (8), did not work. The statement, "There is a chair in the room" could not be translated into a logically equivalent set of sense data statements in the first order predicate calculus. Philosophers gave up on the idea that there was a "basement" language from which all other knowledge of the world, captured in propositions, could be formulated.

Famously, the later Wittgenstein, in his transforming opus Philosophic Investigations (9), pointed out that there was no basement language. Rather, language about legal proceedings could not be translated into logically equivalent sets of statements about ordinary human actions. Each "level" constituted a "language game", not reducible to a lower level. Thus: "Kauffman is guilty of murder." requires for its understanding a co-defined set of concepts such as "trail", "jury", "legally admissible evidence", "legally competent to stand trial"...that cannot be translated or "reduced" into sets of statements about ordinary human actions.

This step is critical, for it says that there is no logical procedure, surely no first order logic, to get from a lower level language game, here normal human action, to a higher level language game, here legal language. But then there is no first order logic "algorithmic procedure" to get from the lower to higher language. Yet we learn legal language. This is one line of argument that the human mind is not merely algorithmic.

Despite some philosophers giving up on a basement language, the early cyberneticians, W. McCulloch and W. Pitts, in 1943 published a seminal paper that would lead to the contemporary theory of neural networks and "connectionism".

McCulloch and Pitts showed that in a network of on/off formal neurons, constructed in a feed forward network, N formal neurons per row and M rows, and in which the input row "neurons" could be placed in any arbitrary combination of "1" and "0" states, the network, with arbitrary threshold Boolean functions such as *and*, *or*, and *not*, could compute any logical function on the "states" of the input neurons.

Implicitly, they identified the "1" or "0" state of a formal neuron with the truth or falseness of a Russellian sense data statement, such as, "For Kauffman, 'A flat now' is true", which might be encoded by a "1" on the first neuron in the input layer to the feedforward network of formal neurons.

More generally McCulloch and Pitts considered networks with feedback loops.

They entitled their paper, "A logical calculus of the ideas immanent in nervous activity" (10).

In this step, McCulloch and Pitts set the stage for the now generally accepted view in computer science, neurobiology, and much of the philosophy of mind, that an "idea" in the mind was logically identical to the on or/off states of a set of formal neurons, or in contemporary neurobiology, with the axonal firing or not of members of a set of "consciousness neurons".

Note that McCulloch and Pitts chose the terms, "immanent in nervous activity". In some magical way, the sense data features, or sense experiences, or "qualia" are "slipped" into the 1 and 0 behaviors of the formal neural net.

Note further that this conceptual move: 1) assumes that there is a basement language, captured in the "1" and "0" states of the formal neurons. 2) Has, with Russell, thrown away the Unity of ConscIousness and will have to reconstruct it. In contemporary neurobiology this issue has returned as the famous "binding problem" ie how does the firing of unconnected "consciousness neurons" become bound into a unity of consciousness, or more simple examples such as this, from F. Crick's *The Astonishing Hypothesis* (1): Suppose I see a yellow triangle and blue square. Suppose "yellow", "triangle", "blue" and "square" are, in fact, processed in different, unconnected, areas of the brain. How do "yellow" and "triangle" become bound together, while "blue" and "square" become bound together?

Following the logic of McCulloch and Pitts, the early hope was brain "grandmother cells" that fired if and only if you saw a combination of features, sense data, that equaled your grandmother. Now reconsider the number of relational features of your visual field. How many grandmother cells would be required, each to encode by firing "if and only if" presented with one of each of the possible combinations of up to, say 30 features at a time, out of say 10,000 features you can discriminate? The answer is (10,000) Choose (30), i.e (10,000!) / 9,9770!) x (30!) a vast number. Crick (ibid), concludes that the idea does not work, it would take more than the 10 to the 11th neurons to encode all the sets of relational features you see.

One current hope is a 40 Hertz oscillation in the brain. The idea is that if "yellow" and "triangle" neurons fire at the same phase of the oscillation they will be bound, and if "blue" and "square" fire at a different phase, they too will be bound. Well, maybe, but how do we squeeze maybe trillions of combinations of relational degrees of freedom into different phases of a 40Hertz oscillation? I find it implausible. While detailed work on binding is beyond the scope of this chapter, in general the issue remains binding anatomically unconnected classical physics neurons and their presumed qualia, or experiences.

Note that this binding problem arises, descendant from Russell, with the idea of sense data and sense data statements, true or false, as a *digital and propositional encoding* of our experience of the world in our Unity of Consciousness. Below I will offer an unexpected *analog and non-propositional* encoding which may solve the binding problem.

But there is another deeper issue: McCulloch and Pitts, and all later neural network theory, cannot meet Wittgenstein's language game argument that there is no "basement language" and the learning of higher language games cannot be based on algorithmic procedures from that basement language.

Despite the warning of Wittgenstein, connectionism has flowered, much along the ideas above, but with important improvements such as Back Propagation (11), and Hopfield Networks (12), with attractors encoding classes or memories and content addressable memory. These are now the basis of voice recognitions systems around the world. But the language game problem remains unsolved, so mind seems not to be algorithmic on this ground.

I point to another important line of evidence that the mind is not algorithmic. I ask you to name all the possible uses of screwdrivers: screwing in screws, opening paint cans, tied to the end of a stick to spear fish, rented to locals to spear fish and you take 5% of the catch...Is there a statable list of the possible uses of a screwdriver for all possible purposes? I think not. How would we construct such a list? Know we had completed the list, or at least made it "infinite but recursively enumerable"? Yet we find new uses for screwdrivers and other artifacts all the time. This is the famous "frame" problem of computer science, never solved algorithmically. I believe there *is no bounded or recursively orderable set of functionalities of human artifacts for all possible purposes*, yet we literally discover and invent them all the time in the evolution of the econosphere. We routinely solve the frame problem. If so, the human mind is not always algorithmic.

I note that R. Penrose, in *The Emperor's New Mind* (13), and *Shadows of the Mind* (14) also argues that the human mind is not always algorithmic based on its capacity to prove incompleteness theorems such as Godel's theorem and the Halting Problem. I join Penrose, who precedes me, but on different grounds, in thinking the mind is not algorithmic and join him in thinking that quantum mechanics is related to consciousness.

Mind, Consciousness, and the Mind as Machine

Two major positions can be taken with respect to mind as a classical physics, and further, a discrete space, time, and state algorithmic computational machine with inputs from a discrete space, time and state environment. First, we are not conscious at all, but are zombies. This view is discussed by Daniel Dennett in *Consciousness Explained* (15), which is, in part, a sophisticated form of logical behaviorism making use of an extensively developed computer science framework. A contrary argument is made by John Searle in his debated but famous Chinese Room argument which claims to show that mind is not a Turing machine, which is merely syntactic in its manipulation of symbols having no semantics, hence the Turing machine cannot experience the meanings of words (16).

In one form or another, the view of the mind-brain system as a network of classical physics neurons, with continuous variables, and continuous time, interacting in classical physics causal ways via action potentials, vast networks with classical physics inputs and outputs, is the dominant view today. Gerald Edelman, *Bright Air, Brilliant Fire* (17), Francis Crick, *The Astonishing Hypothesis* (1), John Searle, *The Mystery of Consciousness* (16), and most working neuroscientists hold this view. According to Searle, Functionalists such as H. Putnam and D. Lewis are "property dualists" who see mental terms such as "believe" as constituted by a classical physics causal network, whether made of neurons or beer cans. Searle asserts that functionalists do not mean by mental terms the actual experience of, for example, pain (16). These two paragraphs cannot characterize the vast scholarly work above, yet these efforts neither answer Descartes, introduced just below, nor finds a home for consciousness itself.

Then whence consciousness, experience, qualia? A popular view is that at some level of complexity of a network of logic gates, whether electronic, water bowls pouring into one another above and below a 0/1 threshold, or classical physics continuous time and state neurons, consciousness will "emerge". It is popular to point out that a single H2O molecule is not wet, but a sufficient collection of them is. So too, consciousness can emerge.

Perhaps consciousness can so emerge, but here is the first deep problem. If the emergent consciousness is a classical physical "process", for example an electromagnetic field as some argue, then it is a deterministic classical physical system. Consider Newton's three laws of motion and universal gravitation, and billiard balls moving on the table. The boundary conditions of the table and current positions, momenta and diameters of the balls entirely determine the entire future trajectory, perhaps deterministic chaos, of the sets of balls.

But if the mind-brain is a deterministic machine, we can have no ontologically real and responsible free will. I walk down the street, kill the little lady with a frying pan, but I am not responsible. I was physically determined to whack her. Even in the face of deterministic chaos I have no ontologically real responsible free will, merely perhaps the epistemic illusion of one.

Thus, the familiar view, derived from Turing and Russell, may be right, consciousness may be a classical physical "something", but we buy it at the price of no ontologically real responsible free will.

It is a huge price to pay. I will offer below a set of ideas that appear to afford us, among other things, an ontologically responsible free will.

There is another huge set of problems, derived from Descartes in 1637 in his Discourse on Method. Descartes postulated a famous dualism (18): Res cogitans, thinking stuff, and Res extensa, his mechanical world view which led, a century later to Newton and celestial mechanics, and thence to classical physics.

But the problem immediately arose how Res cogitans is connected to Res extensa. Descartes proposed the pineal gland. The idea does not work.

Given Newton, here is the issue: If the brain is a deterministic dynamical system, like the billiard balls on the table, then the current state of the brain is entirely sufficient for the next state of the brain. Then there is *nothing for mind to do. worse, there is no way for mind - experiences - to act on brain!* What should mind do, some- magical-how cause the billiard balls to swerve despite the sufficiency of Newton's laws?

This central problem arises due to the *causal closure of classical physics*. It is due to causal closure that we claim Newton's laws, plus the initial positions and momenta and diameters of the billiard balls and boundary conditions, plus Newton's laws in differential form, once integrated, are entirely sufficient to yield the entire future trajectory of the balls on the table.

Thus, the Turing model of the Machine Mind leaves us with no free will, and mind, experiences or qualia, if they can arise at all, as unable to affect the classical physics machine aspect of the mind-brain system. We retreat to mind as a mere epiphenomenon, of no effect in our actions as humans, or a "compatibilism" which rejoices that at least as deterministic systems we can train one another to be moral machines.

In truth, we have been stuck with this cycle of problems since Descartes. Turing machine minds are frozen in the same way.

If the central problem above is due to the causal closure of classical physics, then I believe we must forsake the limitations of classical physics and purely classical physics "consciousness neurons" for a view that embraces the non-determinant behavior arising from quantum mechanics.

I turn now to such a radically different approach to the mind-body problem. It will take us through open quantum systems, the "Poised Realm" between open quantum and classicality for all practical purposes, FAPP, to non-determinate, hence non-algorithmic, yet non-random Trans Turing systems beyond Turing, to my tentative postulate about a new dualism, ontologically real Res potentia, the realm of the Possible, and Res extensa, the realm of the Actual, linked - hence united - by quantum measurement. This postulate is also an interpretation concerning what the unmeasured Schrodinger wave is "about", where we have had no idea since the Schrodinger equation in 1927 (19). The postulate of Res potentia leads to a resulting idea of consciousness as a participation in Res potentia, ie in ontologically real Possibilities and strengthens the independent hypothesis that qualia, i.e. conscious experiences, are associated with quantum measurement. Most of what I shall say is independent of a real Res potentia.

But there is more: We escape the digital "propositional" model of mind with the realization that a quantum wave process in a potential well knows in an analog, not propositional or digital, way its potential well boundary condition or "context", as part of solving the binding problem. I will link this analog "knowing of qualia" to quantum entanglement among many synapses in the brain as candidate loci of quantum behavior, and *quantum measurement* of those entangled degrees of freedom to achieve non-local EPR high correlations (20), hence "binding" of vastly many qualia, one per measurement, to solve the binding problem and achieve the Unity of Consciousness.

Answering Descartes

With the discovery that chlorophyll wrapped by its chromophore bearing antenna protein can be quantum coherent for 700 femtoseconds or more,(21), "quantum biology" is emerging. I believe, however, that quantum coherence may be only a small part of quantum effects in biology. We biologists may find ourselves learning and collaborating with quantum physicists, and quantum chemists, in untellable ways. This part of the chapter is an attempt to see into this new territory.

Closed Quantum Systems and the Two Slit Experiment

Many readers will be familiar with the famous two slit experiment (22). A photon gun emits photons, say one per minute, at a screen with two slits close together and behind the screen is a photodetector, say a film emulsion. If either slit is covered, one obtains a bright spot on the photodetector behind the open slit. Stunningly, if both slits are open, one obtains the famous bars of light, dark, light, dark.., the interference pattern. No classical objects, such as classical particles, can yield this result. It is the hallmark mystery of quantum mechanics, QM.

A classical analogy helps understand the subsequent time dependent linear Schrdodinger equation of QM. Imagine a sea wall with two gaps, and a beach beyond. Let a series of plane waves approach the wall. As it passes through the gaps, each wave yields two semicircular wave patterns that approach the beach. If these semicircular patterns overlap at the beach, there will be points on the beach where the crests of the two wave patterns coincide, yielding a higher wave crest. Similarly there will be beach points where the troughs of two waves coincide yielding lower troughs. But there will also be points on the beach where the peak of one wave coincides with the trough of another wave and the two will cancel entirely.

The Schrodinger time dependent linear wave equation produces similar waves. Where peaks and peaks coincide, or troughs and troughs coincide, one obtains a bright bar of photons in "constructive interference". Where peaks meet troughs, they cancel yielding dark bars in "destructive interference" and hence the interference pattern. An "action" variable in the equation keeps track of the phases in time and space of the Schrodinger waves.

Quantum "weirdness" arises due to the linearity of the equation, for sums and differences of solutions are also solutions. This linearity permits the famous Schrodinger Cat puzzle in which a cat in a box, prior to measurement, is *simultaneously* both dead and alive.

It is notable that, since 1927, no one knows what is "waving" in the Schrodinger wave equation. Meanwhile, von Neumann's axiomatization of quantum mechanics (23), includes this propagating Schrodinger wave and the mysterious quantum measurement process. Here each wave has an amplitude. The *square* of the modulus of an amplitude, called the Born rule (24), yields the *probability* that that amplitude will be measured in von Neumann's Process 1, or "R" process with its controversial "collapse of the wave function" of many amplitudes to only one, which can become classical as in the spot each photon makes on the screen of the two slit experiment. In general, there is, to the best of my knowledge, no agreed derivation of quantum measurement from within QM.

Open Quantum Systems

The emergence of the classical world from the propagation of the Schrodinger wave equation is a deep mystery. One of the current best hypotheses requires distinguishing a quantum "system" from its "environment" yielding an "open quantum system" and its "environment". The key idea is that phase information within the open quantum "system" can be lost, acausally, to the quantum environment. This process is called "decoherence" (25). Then, within the system, the "action" gradually loses information about where the peaks and valleys of the Schrodinger wave "are", so constructive and destructive interference cannot happen, nor can interference patterns. This interference hallmark of quantum effects is gradually lost and classicality is approached arbitrarily closely, reaching classicality "for all practical purposes", FAPP.

Decoherence is well established experimentally. It disrupts quantum coherent qubit behavior in quantum computers.

Critically, decohrence is yielding new physics. First decoherence takes time. A typical time scale is a femtosecond. During that time phase information is being lost from the quantum system. The Schrodinger wave equation is time reversible. But decohrence is a dissipative process, so is not fully describable by the Schrodinger equation. New physics is expected and found.

I give three examples of this new physics. We are all familiar with the radioactive decay half life, due to closed quantum system Poisson distributed decay of the radioactive nucleus, whose integral is the familiar half life of exponential decay. In the confirmed Quantum Anti Zeno Effect, the decay is faster than any exponential (26). New physics.

Of interest to us as biologists, decoherence can alter the rate of chemical reactions (27). Decoherence happens in cells. What are the implications for molecular, cellular, neural, biomedical, drug and other behaviors? We don't yet know.

An essential feature of decoherence is that the weird superposition states, the cat simultaneously dead and alive, decohere very rapidly, leaving what are called one or more "pure states", if more than one, this is called a mixed state. Thus the cat is either dead or alive, but not simultaneously both. We don't know which until quantum measurement (Seth Lloyd pc, Miles Blencowe, pc).

Recoherence, including to a new superposition state, is possible for open quantum systems. i. Several papers by Paz et. al.,(28,29) and Briegel (30,31), show that a quantum entangled state can decohere to classicality FAPP and recohere again. ii. Imposition of a classical field can induce recoherence (32). iii. The Shor quantum error correction theorem (33), proves that if in a quantum computer some qubits are partially decoherent, measurement can be done and information injected, correcting the qubits back to full coherence.

In summary, and stunningly, for open quantum systems it is just becoming known that both decohrence to classicality FAPP and its *reverse*, recoherence, perhaps to a new quantum coherent superposition state, can occur.

Then, in principle, quantum degrees of freedom, including biomolecules, can "hover" between open quantum behavior and classicality FAPP. It is right to stress, as above, that this may have very large implications for the actions of molecules in cells, and drug discovery, design, and action. After all, we treat biomolecules as classical. We may be wrong.

The Poised Realm

Gabor Vattay, a quantum physicist at Eotvos Univesity Budapest, Samuli Niiranen, a Computer Scientist at the

Tampere University of Technology, Finland, and I, have proposed "The Poised Realm" between fully coherent quantum quantum behavior in *open* quantum systems and classicality FAPP. Picture a two dimensional coordinate X, Y system. The Y axis rises from the origin, where there is open quantum coherent behavior, via decohrence, to classicality FAPP up the Y axis, and via recoherence down the Y axis to open quantum coherent behavior. The X axis is new, comprising "order", "criticality" and "chaos". The two axes box in the Poised Realm. The X axis, order, criticality, and chaos is well defined in the classical limit and now is being extended to embrace partially open quantum behavior in the presence of different extents of decoherence and recoherence.

Motion out the X axis from the origin, characterized classically by a frictionless pendulum, can be obtained in at least two ways. The first concerns the "Hamiltonian" of the classical system. A pendulum is perfectly ordered. If released from different initial heights, the frictionless pendulum describes roughly circular orbits in a coordinate space of position and velocity. These circular orbits are parallel, hence neither converge nor diverge. Mathematically, this lack of divergence or convergence is described by a 0 valued Lyapunov exponent. As one moves out the X axis, the Hamiltonian of the system changes. In the ordered regime, the Lyapunov exponent remains a constant 0. But when the Hamiltonian is deformed enough, at "criticality" the Lyapunov exponent becomes slightly positive, the onset of divergence of flows in state space constitute chaos. As the Hamiltonian is modified further, the Lyapunov exponent becomes more positive. This kink at "criticality" is a "second order phase transition", and well established (34).

A second means to move out the X axis consists in using a "kicked quantum rotor". A quantum rotor is a one dimensional hoop of states around which a quantized electric charge rotates. It can be kicked by a laser, with intensity K. As K increases in intensity, Vattay (pc), has shown that at first there are many amplitudes propagating, then few, then a single amplitude transforms to "classical" diffusive behavior in momentum space (35).

This classicality is reversible if K is decreased or the Hamiltonian is changed.

Thus, classicality, presumably FAPP, can be *reversibly* achieved up the Y axis or out the X axis.

The Non-Algorithmic, Non-Determinate, Yet Non-Random Trans -Turing System.

I recall here the fully algorithmic Turing machine described above. Several points, sketched above, are essential. First, all contemporary computers are based on the Turing Machine. Second, the Turing machine is *completely definite*. It is the perfect instantiation, restricted to discrete space, time, and state, of classical physics and Descartes' Res extensa machine world view. iii. This definite behavior of a Turing machine is the definition of algorithmic behavior. iv. Critically, a major contemporary view in neuroscience and computer science and much of the philosophy of mind is that the mind-brain system *must be* algorithmic - some huge system of interconnected logic gates or, more broadly, continuous time and state classical physics neurons firing.

I now describe non-algorithmic, non-determinate, but also non-randomTrans-Turing systems. None has been constructed. I believe they are constructible. More the mind-brain system may be not only a vast *non*-algorithmic, non-determinate system, in contrast to classical physics in general, but also a non random Trans-Turing System. More broadly, classical physics is state determined. The mind brain system may be partially open quantum and Poised Realm, hence, via decoherence to classicality FAPP, or via quantum measurement, the mind-brain system may not be a state determined system.

The central ideas are simple. A Trans-Turing System, TTS, "lives in" the Poised Realm, and perhaps involves quantum measurement in the Poised Realm. i. There are quantum degrees of freedom propagating in short lived superposition states that decay rapidly due to decoherence. But these short lived superposition states undergo constructive and destructive interference and will be one basis for a *non*-Determinacy in the Trans-Turing system when coupled to decoherence to classicality for all practical purposes, FAPP, or quantum measurement. Thus TTS are not algorithmic, not determinate and not state determined, in contrast to a Turing machine.

Second, either via decoherence or motion out the X axis or both, quantum degrees of freedom become classical FAPP or via quantum measurement, become classical "Simpliciter". Both decoherence and measurement are acausal and yield the non-determinant behavior of the Trans-Turing System.

Third, there are, in addition, coupled classical degrees of freedom in the TTS.

Fourth, when quantum degrees of freedom, and either superposition states or pure states become classical FAPP, or are measured, that *alters* in different specific ways the effects of the now classical degrees of freedom on one another, thus alters the non-random collective dynamics of the coupled classical degrees of freedom. In turn this altered non-random classical behavior alters non-randomly the behavior of remaining quantum degrees of freedom.

Fifth, in turn this non-random alteration of the behavior of the remaining quantum degrees of freedom alters non-randomly which of the open quantum degrees of freedom decohere or move out the X axis to classicality FAPP. In particular, higher quantum amplitudes tend to decohere with higher probability. So non-randomly altered quantum behavior, including altered constructive and destructive interference, alters non-randomly which amplitudes become higher, thus alters non-randomly which amplitudes decohere to classicality FAPP.

Sixth, in turn, classical FAPP degrees of freedom can recohere, for example, driven by a coherent electromagnetic field whose intensity and period distribution can be tuned non-randomly thereby injecting information. The recoherent degrees may achieve a new controlled superposition state, thereby altering non-randomly the constructive, destructive, and pure states behaviors among themselves and other quantum amplitudes, thereby non-randomly affecting which amplitudes achieve higher amplitudes and tend to decohere, and also non-randomly altering the behaviors of the coupled classical degrees of freedom in the TTS.

These six are the building blocks of a Trans-Turing System.

A part of a TTS has been realized in a computation by D. Salahub, a quantum chemist at U Calgary and colleagues, in JACS. Salahub et. al.,(36), considered a quantum system of many nuclei and many electrons. The system consists of two potential wells, say A and B. The vertical Y axis is energy. The X axis is a chemical reaction coordinate. The two potential wells overlap at some point in the X and Y plane, in what they call the "seam region". Here at this seam the nuclei are in a superposition of states, simultaneously A and Not A, B and Not B. Via gradual decoherence the nuclei fall into one of the minima, either well A or well B, and become classical FAPP. But in turn this alters the effect of the now classical FAPP nuclei on the electron cloud which does not rapidly decohere. Thus, if the nuclei are now in well A the electrons behave differently than if the now classical nuclei FAPP are in well B and the electrons behave differently if the nuclei are still a superposition in the seam region.

This model is the first instantiation in quantum chemistry that I know in which some quantum degrees of freedom, here the nuclei in a superposition of A and Not A and simultaneously B and Not B, decohere to classicality FAPP, to well A or well B, and thereby alter the behavior of the remaining quantum degrees of freedom, the non-decohering electrons.

A more refined calculation would allow the many nuclei in this system to decohere in some sequential order. As they do, the newly classical FAPP nuclei will yield a sequential alteration in the behavior of at least the electrons and probably the remaining open quantum system superposition nuclei, as well as the other now classical FAPP nuclei. That research lies in the future as does study of such a system if the classical FAPP nuclei can be made to recohere to some perhaps new superposition state, perhaps by an external field, perhaps by interactions of many such subsystems within a molecule.

The essential points about Trans Turing Systems are:

i. Their behavior is not Turing definite, both because of constructive and destructive interference of superposition states, followed by falling to a classical FAPP state where high amplitudes preferentially decohere, and remaining quantum pure states will also decohere probabilistically or by quantum measurement. Further, the total constructive and destructive interference behavior, and further controlled recoherence behavior, alter non-randomly which amplitudes achieve high amplitude so decohere preferentially to classicality FAPP with what probabilities, or are quantum measured, by the Born rule, with what probabilities. The ongoing behavior is not definite, hence NOT algorithmic. The behavior is not state determined. The behavior is also non-random.

ii. The above behavior is, as noted, not "quantum random", as in the case of radioactive decay, for a further reason: The classical degrees of freedom have their own Hamiltonian, hence non-random dynamics, which may, in addition, affect non-randomly the behaviors of the quantum degrees of freedom, hence which quantum amplitudes, via constructive and destructive interference, become high amplitudes and preferentially decohere and when or are preferentially measured via the Born rule. The behavior is both non-deterministic, and non-random.

The TTS may receive quantum, open quantum, Poised Realm, and classical inputs and output open quantum, Poised Realm, and classical output behaviors. So it is a non-algorithmic , non-deterministic via decoherence to classicality FAPP or quantum measurement, yet non-random, information processing system. Consequently if TTS, as single or coupled systems are constructible, perhaps in liposomes, or nano-devices, we have a new non-algorithmic, not state determined, and not random "device", unlike a Turing machine or logic gate, or deterministic classical physical system to consider for the mind-brain system. We no longer are almost forced to the conclusion that mind-brain *must be* classical physics, definite, and either discrete time and state logic gates or continuous time continuous variable deterministic "consciousness neurons, coupled into a huge network. TTS may also take us far beyond the Turing machine technologically.

A Responsible Free Will

As noted above, the view that consciousness emerges from a vast network of classic physics logic gates or classical physics neurons may be entirely correct. However, it has a big price: We are deterministic so have no ontologically real responsible free will. Such a system could exhibit chaotic behavior, yielding the "illusion" of free will, but such a free will would not be ontologically real, for the classical physics neural system remains deterministic.

But there is another horn to this free will dilemma if we seek an ontologically real and responsible free will and then try to use standard quantum randomness. I have a radioactive nucleus in my brain, I walk down the street, the nucleus randomly decays, and I kill the little old man so my "free will" is ontologically real due to quantum indeterminism. But killing the old man is not my fault, just random quantum chance! I have no *responsible* free will if we use quantum randomness.

But a Trans-Turing system is both *not* deterministic, hence not algorithmic, and *not* quantum random, it is something entirely new. I hope this can break the horns of the standard responsible free will dilemma and allows for an ontologically real and responsible free will. I believe more is needed, building upon the idea of Ross Ashby's famous homeostat (37), with its subset of "essential (classical physics) variables" that must be kept in bounds, to provide an internal "goal state" for the total system, to begin to yield a non-random but non-deterministic responsible free will.

This starting sketch, even if right, is inadequate. There is no mention of some analogue or actuality of sensory inputs, motor outputs or the capacity of a coupled Trans-Turing System, or set of entangled TTS systems, joined to the classical aspects of the brain, presumably classical physics neural networks, to classify its environments and act appropriately given goals and subgoals. Below, in proposing the testable hypothesis that qualia are associated with quantum measurement, it seems that "exprериences" have as a natural dual, that which experiences, the rudiments of an

“I”.”Agency”, on this view, is an elaboration of these rudiments in the total mind-brain system.

I note that R. Penrose (13,14), seeks a non-deterministic, non-algorithmic, yet non-random behavior of consciousness via a modified non-deterministic, so non-algorithmic, yet non-random quantum measurement process, “objective reduction”, which might be associated with quantum gravity. Unlike Penrose, who may surely be right, I seek the same non-deterministic, so non-algorithmic, yet non-random behavior in Trans-Turing systems operating in the Poised Realm.

Answering Descartes: How Can Mind Act On Brain

Due to the causal closure of classical physics, we have remained frozen with the Cartesian problem for 350 years. Mind has nothing to do and no way to do it. I believe that open quantum systems and the mind-brain system as one or trillions of interlocked Trans-Turing systems may afford an answer to Cartesian dualism, for it breaks the causal closure of classical physics. Decoherence is an *acausal process*. Thus if the mind brain system lies in the poised realm, decoherence of “mind” to classicality FAPP allows “mind” to have *acausal consequences for brain*, without acting causally on brain. We have indeed escaped the causal closure of classical physics.

But we want mind to do this many times in our lives. Trans-Turing systems, living in the Poised Realm, where recoherence, perhaps to new superposition states, allows mind to repeatedly decohere to have acausal consequences for material brain.

Quantum measurement can occur in Trans-Turing systems. But quantum measurement, von Neumann’s Process 1 or “R” process, is also acausal, and also allows mind to have acausal consequences for brain. More, even should von Neumann’s Process 1 or “R” depend upon the Born rule and his square of the amplitudes to achieve the probability of its acausal measurement, the ongoing behavior of the Trans-Turing systems modifies *non-randomly* which amplitudes are propagating and which achieve high amplitudes and tend to decohere or be measured, so the total behavior is non-random. Once measured a classical degree of freedom can flower again into quantum behavior again, allowing repeated acausal mind-brain action. The non-random but non-determinant total behavior may support a responsible free will.

Res Potentia and Res Extensia Linked by Quantum Measurement

I now come to the most radical proposition in this chapter. It can be false and the remainder of this chapter stay largely intact. I am, with proper hesitation, about to propose a new dualism, Res potentia, the realm of the ontologically real Possible, and Res extensa, the realm of the ontologically real Actual, linked - hence united - by quantum measurement. The very basis of this is quantum mechanics itself.

I turn first to the late 19th Century American philosopher C.S. Pierce (3). He noted that Actuals and Probables obey Aristotle’s Law of the Excluded Middle. Here it is: The table is or is not in the room. There is nothing “in the middle”. Hence the statement, “The table simultaneously is and is NOT in the room” is a contradiction, always false. Now consider: “The probability of 5234 heads out of 10,000 fair coin flips is simultaneously 0.245 and is not 0.245”. It too is a contradiction, always false. Classical physics obeys Aristotle’s Law of the Excluded Middle. But, said Pierce, “Possibles” evade the law of the Excluded Middle. “A is possibly true and A is possibly not true.” is NOT a contradiction.

Now consider Richard Feynman’s (2), “sum over all possible histories” formulation of quantum mechanics, agreed by all to be an equivalent formulation.”A photon on its way through the two slits, simultaneously takes all possible pathways through the two slits to the photoreceptor.” It follows that the single photon “simultaneously possibly *does* and possibility *does not* pass through the left slit”. This is *not a contradiction*.

The critical implication is that Feynman’s formulation of quantum mechanics *evades* Aristotle’s Law of the Excluded Middle. Therefore, I claim, Feynman’s formulation of quantum mechanics is fully interpretable in terms of ontological *real* Possibles, Res potentia. The unmeasured Schrodinger wave concerns Res potentia. Res potentia proposes an answer to what the unmeasured Schrodinger wave is “about”.

This is a huge step, not to be taken lightly. I note that Aristotle himself toyed with the reality of “potentia”. And British philosopher Alfred North Whitehead in Process and Reality, 1929,(4), proposed ontologically real Possibles which gave rise to ontologically real Actuals which gave rise to ontologically real Possibles. P -> A -> P -> A.

The idea may be radical, and may be right, but I am not the first to propose it. We will find evidence consistent with the reality of Res potentia below in the Conway Kochen Strong Free Will Theorem. Further, outstanding quantum physicists are very close to the concept of Res potentia. I quote Dieter Zeh:

"in classical physics you can and do assume that only one of the possibilities is real (that is why you call them possibilities). It is your knowledge that was incomplete before the observation. Mere possibilities cannot interfere with one another to give effects in reality. In particular, if you would use the dynamical laws to trace back in time the improved information about the real state, you would also get improved knowledge about the past. This is different in quantum theory (for pure states): In order to obtain the correct state in the past (that may have been recorded in a previous measurement), you need all apparent "possibilities" (all components of the wave function - including the non-observed ones). So they must have equally been real." (38).

Clearly Zeh is saying, “possibilities”... “must have been equally real.” Res potentia removes the quotes from “possibilities” to propose an ontologically real Res potentia.

More, a founder of quantum mechanics, W. Heisenberg, often spoke of “Potentia” sometimes as “Probabilities” (39), sometimes as “Possibilities” (40), as a separate ontologically real realm along with ontologically real Actuals. I am following Heisenberg with my Res potentia as a realm of ontologically real Possibles.

See M. Epperson (41), for a cogent discussion of many quantum authors and an ontological dualism based on real

Actuals and real "Probables" which DO obey the Law of the Excluded Middle. I stress again that unlike Descartes Res cogitans and Res extensa, never united, Res potentia and Res extensia truly *are* united by quantum measurement

What *is* Consciousness

Philosopher of mind Jerry Foder quipped that "Not only have we no idea what consciousness "is", we have no idea what it would be like to have an idea what consciousness "is" (42).

To my surprise, Res potentia leads to an obvious idea about what consciousness IS. Consciousness is a participation in The Possible, an ontologically real Res potentia.

I offer three pieces of evidence:

1. Where is the possibility I will skate across town reading the NY times and not be hit by a car? I think we all feel that the "possibility" itself is not spatially locatable, it is not spatially extended.
2. Now consider your experienced visual field. Where is your experienced field located? I think we all sense that our experienced field is not located spatially. It is not spatially extended.
3. Just below I will propose that qualia are associated with quantum measurement and further below hypothesize that entanglement of many quantum degrees of freedom, perhaps among neurotransmitter receptor molecules in anatomically unconnected synapses in the brain, may, by each being quantum measured, yield causally non-local Einstein, Podolsky, Rosen, EPR, high correlations of now bound qualia (20), to solve the "qualia binding problem" in neurobiology. Non-local correlations are "non local" because they are beyond speed of light signaling and "instantaneous", hence also "non-spatial".

This non-spatial character of "Possibilities", Experience and Non-Local EPR quantum measurements may be happenstance or a clue. Taking this parallel as a clue may lead us forward in new ways.

Qualia may be Associated With Quantum Measurement

Where is it natural to locate experience itself, the blueness of blue, the taste of wine, qualia? I suggest qualia are associated with quantum measurement, ie Possible "becomes" Actual, Possible -> Actual. As we shall see, this leads to testable consequences. It is not a bald hypothesis standing alone, for as just noted I will propose below that quantum entanglement among many quantum degrees of freedom in anatomically unconnected synapses, and non-local EPR correlations achieved by a set of quantum measurements of these entangled degrees of freedom may help solve the "qualia binding problem" and the Unity of Consciousness issue. Thus solving the binding problem may require the hypothesis that quantum measurement is associated with qualia. The hypothesis should be testable in the brain. More, entanglement to solve the binding problem is testable. I note that physicist H. Stapp has different but somewhat related ideas (43) See also Penrose (14).

A critical feature of quantum measurement, my physicist friends assure me, is that it has never been derived from within quantum mechanics. Granted Res potentia, such a derivation may be disallowed. "X is Possible" does *not* imply "X is Actual". Our difficulties with such a derivation since 1927 may be ontological, not technical - mathematical. If Res potentia is ontologically real, the same ontological issue may bear on our failure to unite General Relativity and Quantum Mechanics: the "X is Possible" of unmeasured quantum mechanics does *not* imply the "X is Actual" of General Relativity.

On Res potentia, a second feature of measurement becomes equally important. What is the "becomes" of Possible "becomes" Actual? What is the status of "->" in P -> A? It is not a classical becoming like water freezing, nor the unitary propagation of the Schrodinger wave. As a "becoming" it seem not to be an *existing state* at all. Qualia are a "becoming" not an "existence". Nor can "->" be a mathematizable deductive entailing process, for if it were, it would enable deduction from "X is Possible" to "X is Actual", which is invalid if Res potentia is real. Then there is no mechanism for the quantum measurement captured in von Neumann's "ad hoc" Process 1 or "R" projection process.

The above paragraph depends upon the reality of Res potentia. But the proposal of a real Res potentia ties to the recent, 2009, Conway Kochen Strong Free Will Theorem (44), which states that if physicists have free will so do electrons, that the world is non-determinant, that there can be no mechanism for quantum measurement, and that the relevant property does not exist before measurement. This theorem rests on free will for the physicist. But above I have argued that Trans-Turing systems in the Poised Realm, *without relying on an ontologically real res potentia*, may afford an ontologically responsible free will. Responsible free will may well require qualia, experience, which I propose is associated with quantum measurement. This again is a proposal that does not require the reality of Res potentia. But a responsible free will supports the claims of the Strong Free Will Theorem. Conversely, this theorem states that, given the free willed physicist, the world is non-determinant. This is consistent with the hypothesis of the reality of *res potentia*. More, by this theorem, if qualia are associated with quantum measurement, there is no mechanism for that measurement. But measurements yield classical degrees of freedom that, as such, can have classical causal effects on the classical world. Mind, qualia, can, via acausal measurement, act causally on the world classically. Perhaps, as I propose below, neurotransmitter receptors are the loci of quantum measurement and qualia. Then the classical variable consequences could alter post synaptic voltage gate behaviors leading to neural firing or not. In turn qualia themselves emerge as irreducible.

The vice of this view is that it hides the mystery of qualia in the mystery of measurement. The virtue of this "hiding' is that it may explain, at last, why we cannot isolate or pin down an irreducible character of qualia. Philosopher David Chalmers (45), also proposes on independent grounds that qualia are irreducible.

I stress that this hypothesis does not say what qualia *are*.

This hypothesis is testable. Anesthetics bind to hydrophobic pockets in neurotransmitter receptors in synapses (46). If they freeze receptors so they cannot quantum measure, no more qualia can arise. Moreover, Drosophila can be anesthetized by ether. Select for ease of being anesthetized and seek the molecular components involved in easy anesthetization. The normal, or wild type, versions of these molecules may be involved in consciousness and their quantum and quantum measurement properties studied.

If I assume qualia are associated only with measurement, a potential role for unmeasured quantum behavior in the mind-brain system could be unconscious mental processing, which may have classical consequences via decoherence to classicality FAPP, without measurement. Possibly this bears on Libet's results of neural activities 200 or more milliseconds before conscious awareness of a decision to act (47). This too should be testable.

If qualia ARE associated with quantum measurement, it seems natural that the dual of "experience" is that which experiences, a rudimentary "I". From this rudimentary "I" in the entire mind-brain system with its inputs and outputs, my hope is that full "Agency" and an ontologically real and responsible free will can be found.

Standing the Brain on its Head

I begin with a stunning fact. The Box jelly fish, with only a loose neural net, no evolved brain, but eyes that have evolved to see shape and color, swims at five knots adroitly avoiding obstacles (48). An evolved brain is not needed for these feats. Also choanoflagellates, single cell precursors to the animals, have many molecular components of synapses (49).

Many readers of the chapter know the neuroanatomy of the human brain and much of its physiology. In brief, we have about 10 to the 11th neurons, each with an average of 6000 synapses. Cell bodies have descending axons which may or may not branch, but each ends on synapses associated by synaptic spikes on dendrites in arborizations which lead into cell bodies. When an action depolarization potential travels down an axon to a synapse, presynaptic vesicles release one of a set of neurotransmitters, such as GABA, which crosses the synaptic cleft to the adjacent dendrite of the post synaptic neuron, and binds to post synaptic neurotransmitter receptors which are often in clusters of many proteins. In turn, often this leads to opening of an ion channel, a transient flow of ions, and a very short term depolarization or hyper-polarization (excitatory or inhibitory respectively) of the tiny local patch of dendritic transmembrane potential. These local changes flow to the cell body and are summed. If the resulting transmembrane potential at the cell body is more than - 20 mV, an action potential is initiated and travels down the axon. Most neurobiologists think classical physics action potentials in neurons carry a "neuronal code" underlying consciousness.

In Francis Crick's Astonishing Hypothesis (1), he notes in a throw away line, that vast amounts of information about tiny time-space alterations in dendritic transmembrane potentials and behaviors of synaptic molecules are thrown away in neural classical physics action potentials.

What if we consider "standing the brain on its head", and supposing that this vast amount of information in and around synapses and local dendritic regions are the "business end" of the brain- sensory-motor system. This does not vitiate at all the huge amount of work on neural circuitry and classical action potentials and information processing by classical neural action in the brain.

However, it does raise the possibility that the "neural correlates of consciousness" may lie in synaptic and local dendritic, possibly poised realm behavior, possibly in quantum measurement processes.

I note that Beck and Eccles have considered quantum processes in synapses (50)

Quantum Entanglement, Niirnan's idea, and the Binding Problem

Consider, says Crick, a yellow triangle and blue square. Let "yellow", "triangle", "blue", and "square" be processed in different, anatomically unconnected brain areas. How are they bound into yellow triangle and blue square. This is the binding problem. Crick focuses hope on squeezing perhaps millions of distinct sets of features to be bound into different phases of the 40 Hertz oscillation, as I have described.

The first idea I propose is to use quantum entanglement to link quantum processes in different, anatomically unconnected synapses to start to solve the binding problem. Entanglement occurs if a quantum degree of freedom, say a photon, decays into two lower energy photons that go off in opposite directions, even so far apart that even light cannot travel between them in the *interval between quantum measurements of the two entangled photons*. QM says, and it is confirmed over and over, that the *two quantum measurements* will be highly correlated, even though no light or information can have traveled between the two sites. This is "EPR non-local correlation" (20). I stress that in the entangled state, the two photons remain in a *single* quantum state.

I want to try to use quantum entanglement among many synaptic degrees of freedom to try to solve the Binding Problem. Hence, as I have emphasized, it is very attractive to me that these quantum correlations require quantum *measurement* of the entangled degrees of freedom, and I have already supposed that quantum measurement itself is associated with qualia. Then these many entangled degrees of freedom in a *single* quantum state when measured yield qualia that *are* bound. The hypothesis that qualia are associated with quantum measurement does not stand alone, it may afford a part of an answer to the Unity of Consciousness.

Clearly, such entanglement may require long range entanglement among anatomically unconnected synapses and neurons in the brain connecting the "right" set of, say, synaptic molecules. How and whether this may be accomplished is, at present, uncertain, but see below.

Samuli Niianen had a lovely idea. "If you measure the position and momentum a single classical gas particle in a box, do you know about the shape of the box?" No you do not. "But", he continued, "a quantum wave process in a potential well that serves as its boundary condition "knows" about the shape of that potential well, for example in its measured energy spectrum!". He is right.

Think of music in a room and trying to describe air pressure waves using bits. Now think of 1000 differently shaped drum heads well placed in the room. Their patterns of vibrations, ie the eigenfunction spectra of the drums bound to drumheads, “know” the music in the room, and do so in an analog embodied way, not a digital or propositional way. A telephone is not digital either.

This leads to the idea that the brain’s sensory system and the whole brain, may tune the synaptic or local dendritic transmembrane potentials in tiny time-space regions of the brain, such as synapeses and adjacent local dendritic membranes so they jointly “cover”, like many tuned antennas, the visual scene such that quantum processes in those potential wells, when entangled and measured yield both a Unity of Consciousness and solve the Binding Problem in an analog not digital way.

Two final points. It now appears that increasing the number of entangled degrees of freedom *increases* the quantum EPR correlations. This increase is the opposite of the curse of dimensionality. This helps the binding problem. Second, local actions can alter which quantum degrees of freedom are entangled, perhaps offering an account for serially shifting focus of attention, and might entangle the “correct” set of quantum degrees of freedom for each focus of attention (51).

Can all this be correct? I certainly do not know. But the ideas seem coherent, testable, and jointly seem to offer new purchase on manifold problems.

“Programming Trans-Turing Systems”

We have known about Turing Machines since the mid 1930s and programming the von Neumann architecture for over fifty years. We have no experience with Trans-Turing Systems, TTS. But we face a problem: How would we achieve a TTS that “does something we want”?

There seem to be two approaches. Simulate the TTS on a digital computer and evolve a population of TTS, or a population of interacting entangled, measured, TTS, to yield the behavior desired. This is analogous to the Genetic Algorithm of Holland (5).

Another approach which may be worth considering is creating self reproducing molecular systems, perhaps autocatalytic sets of polymers in dividing liposomes, supplied with energy by pyrophospate or in other ways, and capable of open ended evolution. Recent work shows that: 1) collectively autocatalytic sets arise as the diversity of polymers in a reaction set is increased (52,53). 2) Such systems can undergo open ended evolution (54). 3) Liposomes can grow and divide (55). 4) A collectively autocatalytic set in a reproducing container can yield synchronization of the reproduction of each (56). Experimental collectively autocatalytic sets have been constructed (57). Libraries of stochastic DNA, RNA, peptides, polypeptides and proteins can be made (58), so we can test for the emergence of collectively autocatalytic sets.

It is an exciting prospect that work on the origin of life and work on Trans-Turing Systems may come together. More Darwinian preadaptations among such co-evolving protocells generate new, unprestatable biological functions that maintain one or more such protocells, hence solve the frame problem (59). Co-evolving TTS in protocells may well solve the frame problem too.

Work with minimal cells as vehicles for TTS evolution and co-evolution may be possible (60).

In addition, nanotechnology, perhaps with populations of nano-devices that can be subjected to Holland’s Genetic algorithm (5), may prove useful.

Conclusions

I have argued that classical physics Turing machines as models of the mind are possible, but leave us at best with no free will, and an epiphenomenal consciousness. I believe that we can begin to go beyond Turing, to create non-algorithmic, non-determinate, and non- randomly behaving Trans-Turing systems, living in the Poised Realm, perhaps in self reproducing protocells, perhaps as nano-devices, both open to evolution or co-evolution to achieve useful ends. I propose tentative answers to Descartes about mind and body. Many of the ideas in the Chapter are new science or even radical. They may portend transformations in quantum physics, quantum chemistry, a new Poised Realm behavior of biomolecules hovering between quantum and classical behaviors, a new approach to neurobiology, the philosophy of mind, and the radical possibility of Res potentia with consciousness a participation in The Possible, qualia as irreducible and associated with quantum measurement which also may be irreducible, and entanglement and quantum measurement to achieve a unity of consciousness. I hope these concepts point the way forward for us all.

Acknowledgements

The author was partially supported as a Finnish Distinguished Professor at the Tampere University of Technology by the TEKES Foundation.

References

1. Francis Crick, The Astonishing Hypothesis: The Scientific Search For the Soul, TOUCHSTONE, Simon an Schuster, N.Y. 1994.
2. Feynman, R. P. (1948). The Space-Time Formulation of Nonrelativistic Quantum Mechanics. Reviews of Modern Physics, 20: 367-387.
3. C,S, Pierce Collected Papers Vols I and II, Edited by Charles Hartshorne and Paul Weiss, Harvard University Press, Cambridge Mass.1960.
4. Alfred North Whitehead. Process and Reality: An Essay in Cosmology, Corrected Edition. Ed. D. Griffin and D. Sherburne. Free Press. N.Y. 1978.
5. Holland John, H. Adaptation in Natural and Artificial Systems, University of Michigan Press, Ann Arbor, Mich. 1975.
6. Alan Turing, Can Automatic Calculating Machines be Said to Think?, in Copeland, B. Jack, The Essential turing: The ideas that gave birth to the computer age, Oxford University Press, Oxford, 1952.
7. Bertrand Russell, 1912, The Problems of Philosophy, Oxford University Press, 1997 N.Y.
8. Ludwig Wittgenstein (1921) Logisch-Philosophische Abhandlung, Wilhelm Ostwald (ed.) Annalen der Naturephilosophie, 14.
9. Ludwig Wittgenstein, Philosophical Investigations, Blackwell Publishing Oxford, 1953/2001.
10. McCulloch, W. and Pitts, W. (1943) A logical calculus of the ideas immanent in nervous activity. Bulletin of Mathematical biophysics, 7: 115-133.

11. Paul J. Werbos. The Roots of Backpropagation. From Ordered Derivatives to Neural Networks and Political Forecasting. N.Y. John Wiley and Sons, Inc, 1994.
12. J.J. Hopfield. (1982). Neural networks and physical systems with emergent collective computational abilities, Proceedings of the National Academy of Science of the USA, vol 79, no 8 pp 2554-2558.
13. Roger Penrose, The Emperor's New Mind: Concerning Computers, Minds and the Laws of Physics, Oxford University Press, Oxford. 1989.
14. Roger Penrose, Shadows of the Mind: A search for the missing science of consciousness. Oxford University Press, Oxford, 1994
15. Daniel C. Dennett. Consciousness Explained. Little Brown. 1991.
16. John R. Searle. The Mystery of Consciousness. Th New York Review Books, N.Y. 1997.
17. Gerald Edelman. Bright Air, Brilliant Fire: On the matter of mind. Basic Books, N.Y. 1992.
18. Rene Descartes, Discourse on Method. 1637A.D. Open Court Publishing, Chicago, 1899, Reprint 1962.
19. Schrodinger, E. (1926). An Undulatory Theory of the Mechanics of Atoms and Molecules. Physical Reveiw 28,(6) 1049-1070.
20. A. Aspect, Dalibard, J., and Rogers, G. (1982). Experimental Test of Bell's Inequalities Using Time-Varying Analyses. Phys. Rev. Lett. 44: 1804-1807.
21. A. Ishizaki, Calhoun. T.R. Schlou-Cophen, G.S. , Fleming, G.R. (2010). Quantum coherence and it s interplay with protein environments in photosynthetic electronic energy transfer. Phys Chem Chem Phys. 12 (27): 7319-7337.
22. R. P. Feynman., Leighton, R., and Sands, M. The Feynman Lectures on Physics, Vol 3: 1-8. Addison-Wesley. N.Y.1964.
23. John von Neumann. (1932). Mathematical Foundations of Quantum Mechanics. Beyer, R.T. trans. Princeton University Press. Princeton N.J. 1996 edition.
24. Max Born. Atomic Physics, 8th Ed. Dover, N.Y. 1989.
25. W. H. Zurek. (2002). Decoherence and the Transition from Quantum to Classical - Revisited. Los Alamos Science Number 27: (2002).
26. M.C Fischer, B. Butierrez-Medina, and M.G. Raizen. (2001). Observation of the Quantum Zeno and Anti-Zeno Effects in an Unstable System. Phys. Rev. Lett. 87(4) pp 040402-1- 040402-4.
27. O. V. Prezhdo. (2000). Quantum Anti-Zeno Acceleration of a Chemical Reaction. Phys Rev Lett 85: 4413-4417.
28. J. P. Paz, and Roncaglia. A. J. (2009). Entanglement dynamics during deocherence. Quantum Inf Process 8: 535-548.
29. C. Cormack and Paz, J. P. (2010). Observing different phases for the dynamics of entanglement in an ion trap. Phys. Rev.A. 81: 022306.
30. J. Cai, Popescu, S., Briegel. H. J. (2008). Dynamic Entanglement in Oscillating Molecules. arXhiv:0809.4906v1 [quant-ph] 29 Sept 2008.
31. H.J.Briegel and Popescu. S. (2008). Entanglement and Intra-Molecular Cooling In Biological Systems - A Quantum Thermodynamic Perspective. arXhib:0806.4552v1 [quant-ph] 27 June 2008.
32. C. Mainos. (2000). Laser induced coherence in ultraphoton excitation of individual molecules. Phys. Rev. A 61: 063410-6.
33. W. P. Shor. (1995). Scheme for reducing decoherence in quantum computer memory. AT&Bell Laboratories.
34. R.S. Mackay. Renormalization in area preserving maps. World Scientific N.Y. 1993.
35. G. Vattay (2010). Transition from quantum to classical behavior in kicked quantum rotors as kicking intensity increases. Personal communication.
36. A. de la Lande, Rezac, Levy, J.B., Sanders, B.C., Salahub, D. R. (2011). Transmission coefficients for chemical reactions with multiple states: the role of quantum decoherence. J. Am. Chem. Soc,13: 3883-3894.
37. R. Ashby Design for a Brain: The origin of adaptive behavior. Chapman & Hall. N.Y.1952.
38. D. Zeh. http://www.fqxi.org/community/forum/topic/39 (3rd comment from top).
39. Werner Heisenberg. "The Development of the Interpretation of the Quantum Theory, in Neils Bohr and the Development of Physics, ed. Wolfgang Pauli (McGraw-Hill) N.Y. 1955.
40. Werner Heisenberg. Physics and Philosophy: The Revolution in Modern Science. Harper and Row, N.Y. 1958.
41. Michael Epperson. Quantum Mechanics and the philosophy of Alfred North Whitehead. Fordham University Press, N.Y. 2004.
42. Jerry Fodor. The Mind Doesn't Work That Way: The Scope and Limits of Computational Psychology. MIT Press. 2000.
43. Henry P. Stapp. Mindful Universe: Quantum Mechanics and the Participating Observer. Springer, 2007.
44. J. H. Conway and S. Kochen (2009). The Strong Free Will Theorem. Notices of the AMS 56 (2): 226-232.
45. David J. Chalmers. The Conscious Mind: In Search of a Fundamental Theory. Oxford University Press. N.Y.1996.
46. S. R. Hameroff. (2006). The Entwined Mysteries of Anesthesia and Consciousness: Is there a common underlying mechanism? Anesthesiology, 105: 400-412.
47. Libet, B. Cerebral processes that distinguish conscious experience from unconscious mental functions. In J. C. Eccles and O.D. Creutzfeldt, editors, The Principles of Design and Operation of the Brain, pp 185-205, Springer, 1990.
48. S.C. Morris in Atoms & Eden: Conversations on Religion and Science, Steve Paulson. Oxford University Press. N.Y. 2010.
49. King,N., Hittinger, C.T., Carroll S. B.. (2003). Evolution of key cell signalling and adhestion proteins predates animal origins. Science 301 (5631):361-363.
50. F. Beck and Eccles, J. C. (1994). Quantum processes in the brain" A scientific basis for consciousness. In Naoyuki Osaka (Ed.), Neural Basis of Consciousciousness. Amsterdam, Philadelphila: John Benjamins.
51. Science News Nov 20, 2010. Inducing Entanglement.
52. S. A. Kauffman. (1986). Autocatalytic Sets of Proteins. J. Theor. Bio. 119: 1-24.
53. W. Hordijk, Hein, J. and Steel, M. (2010). Autocatalytic sets and the origin of life. Entropy 12 (7): 1733-1742.
54. C. Fernando, Vasas, V., Santos, M., Kauffman, S., and Szathmary, E. (2011). Spontaneous Formation and Evolution of Autocatalytic Sets within Compartments. Submitted.
55. P.L Luisi, Stano, P., Rasi, S., and Mavelli, F. (2004). A possible route to prebiotic vesicle reproduction, Artifical Life, 10: 297-308.
56. A. Filsetti, Serra, R., Carletti, T., Villiani, M.,and Poli., I. (2010). Non-linear protocell models: synchronization and chaos. Eur. J. Phys. J. B 77: 249-256.
57. N. Wagner and Ashkenasy, G. (2009). Symmetry and order in systems chemistry. The Journal of Chemical Physics, 130: 164907-164911.
58. Stuart Kauffman. Origins of Order: self organization and selection in evolution. Oxford University Press. N.Y. 1993.
59. Stuart Kauffman. Reinventing the Sacred, Basic Books, NY. 2008
60. R.L.Hotz. (2010). Scientists Create Synthetic Organism. Wall Street Journal May 21