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The role of quantum mechanics in cognition-based evolution

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A B S T R A C T

In 2021 I noted that in all information-based systems we understand, Cognition creates Code, which controls Chemical reactions. Known agents write software which controls hardware, and not the other way around. I proposed the same is true in all of biology. Though the textbook description of cause and effect in biology proposes the reverse, that Chemical reactions produce Code from which Cognition emerges, there are no examples in the literature demonstrating either step. A mathematical proof for the first step, cognition generating code, is based on Turing's halting problem. The second step, code controlling chemical reactions, is the role of the genetic code. Thus a central question in biology: What is the nature and source of cognition? In this paper I propose a relationship between biology and Quantum Mechanics (QM), hypothesizing that the same principle that enables an observer to collapse a wave function also grants biology its agency: the organism's ability to act on the world instead of merely being a passive recipient. Just as all living cells are cognitive (Shapiro 2021, 2007; McClintock 1984; Lyon 2015; Levin 2019; Pascal and Pross, 2022), I propose humans are quantum observers because we are made of cells and all cells are observers. This supports the century-old view that in QM, the observer does not merely record the event but plays a fundamental role in its outcome.The classical world is driven by laws, which are deductive; the quantum world is driven by choices, which are inductive. When the two are combined, they form the master feedback loop of perception and action for all biology. In this paper I apply basic definitions of induction, deduction and computation to known properties of QM to show that the organism altering itself (and its environment) is a whole shaping its parts. It is not merely parts comprising a whole. I propose that an observer collapsing the wave function is the physical mechanism for producing negentropy. The way forward in solving the information problem in biology is understanding the relationship between cognition and QM.

1. Introduction

The celebrated biologist JBS Haldane said, "Teleology is like a mistress to a biologist: he cannot live without her, but he's unwilling to be seen with her in public." In saying this, he pinpointed an atmosphere of denial that was to characterize his beloved profession for the next 100 years.

Discussions of purpose in academic papers have been forbidden, yet Levin reports: "'Xenobots' are made of embryonic skin cells from the frog *Xenopus laevis* and have been used as a bio-robotics platform. They are capable of self-assembly and regeneration" (Levin, 2022). "When newt cells are made very large by induced polyploidy, they not only adjust the number of cells that work together to build kidney tubules with correct lumen diameter, but can call up a completely different molecular mechanism (cytoskeletal bending instead of cell:cell communication) to make a tubule consisting in cross-section of just 1 cell wrapped around itself; this illustrates intelligence of the collective, as it creatively deploys diverse lower-level modules to solve novel problems" (Levin, 2022). "When tadpoles are created to have eyes on their tails (instead of in their heads), the animals can see very well" (Blackiston and Levin, 2013). William James said, "Intelligence is a fixed goal with variable means of achieving it." The eye has a *function* of seeing but the tadpole's eye and its entire physiological system exhibit mutual *purpose* of seeing, even when the eye is transferred to the tail. A watch has a *function* which is to tell time, but a watch does nothing comparable to a cell. A cell expresses purposes so wide-ranging and adaptive as to defy any simple description. All cells and tissues are intelligent (Fields et al., 2021; Lyon, 2015; Shapiro, 2021,) and cognitive (Shapiro 2021, 2007; McClintock, 1984; Lyon, 2015; Levin, 2019; Pascal and Pross, 2022) all life forms turn disorder into order. We lack a mechanism to explain what makes this possible.

Levin and Fields report, "The multi-scale competency of life is essential to adaptive function, potentiating evolution and providing strategies for top-down control (not micromanagement) to address complex disease and injury. We propose an observer-focused viewpoint that is agnostic about scale and implementation, illustrating how evolution pivoted similar strategies to explore and exploit metabolic, transcriptional, morphological, and finally 3D motion spaces." (Levin, 2022). Life possesses something special: a willful self-awareness that distinguishes it from rocks and sand dunes and snowflakes.

The standard description of cause and effect in biology has been that Chemistry produces Code, from which Cognition emerges (Marshall, 2021). However there are no examples in the literature to support the first step (Marshall, 2015, 2021; Walker et al., 2017) or the second (Ginsburg 2019; Floridi 2005). Absence of proof is not proof of absence, yet in all information-based systems we understand, Cognition creates

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Code which controls Chemistry. (Marshall and Rinaldi, 2004; 2021). We live in the information age, where agents write software which controls hardware. Causation is never the other way around.

In this paper, I propose that the famous double slit experiment in quantum physics, where the participation of the observer determines the outcome of the collapse of the wave function, dynamically described by Schrodinger's equation - whether the observer sees a particle or a wave - holds the key to the mystery of biology. The observer is the cell. This paper hypothesizes that all living things can collapse a wave function. Wave collapse by an observer would then be the internal mechanism by which biology turns disorder into order.

2. Negative information entropy and Maxwell's demon

In his 1944 book "What is Life?" (Schrödinger, 1944) Erwin Schrödinger introduced the concept of "negative entropy" or "negentropy" to describe the way living organisms maintain order and organization by exporting entropy to their surroundings. Negentropy is not *thermodynamic* entropy in reverse; rather it is *information* entropy (Shannon, 1948) in reverse. It is creating signal instead of noise. One binary choice that creates information is one bit of negentropy (Davies, 2019; Marshall, 2021). Organisms turn disorder into order by generating information through choice. Negentropy requires a minimum energy cost, which is the Landauer limit (Landauer, 1961). An organism's ability to observe and therefore *choose* a physical outcome from a superposition of many states, by directing its attention (valence, defined below) is the Maxwell's demon of biology. Davies says, "The strange calculus of quantum mechanics requires one to integrate *all* available pathways between start and finish; they all contribute to how the particle gets there." He goes on to describe photosynthesis: "Green sulfur bacteria need to do the very best with what they can get and, indeed, efficiencies approach 100 per cent, with little or no energy squandered." (Davies, 2019).

This paper suggests that when some of the most enduring mysteries in biology are reframed slightly, they become identical to QM questions physicists have probed for 100 years. Once seen in that light, we are presented with a new set of questions which I predict will inspire new landmark experiments.

3. Overview of the cause and effect relationship in biology

Weinberg (1992) explores the quest for a final theory in physics, which would unify the fundamental laws of nature into a single, comprehensive framework. Also see (Wills, 2014). Yanofsky says, "For the past three millennia a major goal of science has been to give deterministic rules for all phenomena" (Yanofsky, 2013). An implicit assumption in the natural sciences is that the entire world can be expressed by mathematics. An extreme view states that "all is computation" (Wolfram and Gad-el-Hak, 2003). One might define reductionism as the belief that everything in the cosmos can be reduced to an equation. Laplace (Laplace, 1814) famously desired to "condense into a single formula the movement of the greatest bodies of the universe and that of the tiniest atom; for such an intellect nothing would be uncertain and the future just like the past would be present before its eyes."

4. Reductionism, gödel and Turing's halting problem

Reductionism can be defined as: "The theory that every complex phenomenon, especially in biology or psychology, can be explained by analyzing the simplest, most basic physical mechanisms that are in operation during the phenomenon (Reductionism - Dictionary.com, n.d.)."

In the early 20th century, renowned mathematician David Hilbert announced the Hilbert program (Goldstein 2006) in hopes of providing a complete and consistent axiomatization of all mathematical concepts, thereby establishing mathematics as an exact and certain discipline.

In 1931 Kurt Gödel proved this impossible with his incompleteness theorems (Gödel, 1931; Goldstein, 2006). Incompleteness says a consistent formal system capable of expressing basic arithmetic cannot prove all true statements within its own system. This means that there will always be some truths in mathematics that cannot be proven within the framework of a given system, and that such a system is "incomplete" (Davis, 1965). The axioms of any mathematical system are chosen (Weyl, 2013) and cannot be computed or proven. If an axiom is proven and becomes a theorem, it unavoidably relies on something else that cannot be proven. In geometry it is not possible to prove Euclid's 2nd postulate: "A line segment can be extended in both directions." It presumes without proof that space is infinite. This is an axiom, a rule that seems free of contradictions and everyone agrees to follow (Borsuk and Szmielew, 1960). We "know" it to be true, but we cannot prove it. We only know we have not proven it to be false.

Alan Turing conceptualized the Turing machine in 1936. It operates by reading input from a tape, executing a program, and writing to an output tape. A computer with input, output, and enough memory is essentially a Turing machine. Turing (1936) proved that computers and math functions are deductive, and a computer can calculate any mathematical function. This led to the question of whether we could predict in advance whether the computer would produce an answer to any given problem. Turing proved it is impossible for a general algorithm to exist that can answer this question. This is known as the halting problem (Turing, 1936), and is a key result in the development of my argument. This was a re-statement of Gödel's 1931 incompleteness theorem (Davis, 1965).

5. Hard limits of science

This has direct import to any scientist, because it means that there are many behaviors in the physical world that *in principle* cannot be reduced to computation. In the next section I will show that biology uses QM to get around this limitation. The value of reverse engineering a biological mechanism that transcends computation cannot be overstated. Levin describes a "continuum of agency" which "avails those kinds of minds with a long term version of free will: the ability through practice and repeated effort to change their own thinking patterns, responses to stimuli, and functional cognition" (Levin, 2022).

Logical positivism was a philosophical movement related to Hilbert's program. It emerged in the early 20th century, emphasizing the use of logic and empirical evidence as the basis of knowledge. It held that only statements that can be verified through observation or logical deduction have meaning, and that metaphysics is meaningless. Logical positivism led to proposals that the universe itself is a large computational system and in principle reducible to mathematics (Wolfram, 2002). Gödel's theorem and Turing's halting problem rendered the ideals of logical positivism impossible to achieve (Goldstein, 2006; Davis, 1965), because all systems of logic are based on unprovable (though perhaps reasonable) assumptions. This means that it is impossible to approach any subject without some number of unprovable assumptions.

6. Induction requires cognition: proof

It is possible to prove through Turing mathematics that organisms are agents and not merely computational devices:

1. Mathematical functions and computer programs are equivalent and deterministic
   I. General recursive logic is by definition deductive and deterministic ("General recursive function - Encyclopedia of Mathematics," n.d.)
   II. Turing machines (computers) are equivalent to general recursive logic (Turing 1936)
   III. Therefore, computers are deductive and deterministic

Deductive reasoning (i.e. "23*78 = 1794"; "All men are mortal, therefore Socrates is mortal") can be defined in a straightforward and rigorous way: Any certain conclusion that can be reached via mathematical logic, as stated above. However, inductive reasoning (i.e. "Propose a model of the solar system based on astronomical charts available in 1543"; "Socrates is mortal, therefore all men are mortal") is harder to precisely define. There is no single universal definition of induction, nor there is a "third" form of reasoning; all others such as abduction are combinations of induction and deduction. This leads me to precisely define induction as follows: *Induction is any reasoning that is not deductive.* Induction is any time a question is asked, no proven answer is available, and a guess is made.

2. Deterministic Turing machines are deductive
   i. Inductive and deductive processes as defined above are mutually exclusive
   ii. Processes in classical Turing machines are equivalent to deductive processes
   iii. Therefore Turing machines cannot perform inductive reasoning

Turing's halting problem is the most rigorous definition of inductive reasoning. If deduction is only achieved when the Turing machine halts, then anytime there is a question of *whether* the Turing machine will halt, *when* it will halt, *why* it will halt, *how* to make it halt, *what* will happen when it halts, that is induction. It is not possible for a computer to reason inductively because it is deductive by definition. Only an agent can invoke the halting problem. Thus I define "agent" here as *any entity that can do inductive reasoning.*

Therefore we make the following inference:

03. Negentropy (inductive reasoning, choice) requires agency
   I. Negentropy is choice
   II. Only agents make choices
   III. Therefore, negentropy requires agency

Marshall (2021) discusses this proof in more detail. Wigner (1961) discusses the apparent universality of mathematics in describing physical phenomena. But this can only be true if some caveats are made. Every student has gotten wrong answers on a math test. The paper they wrote the answers on, and the ink on the paper still obey the laws of physics and equations physicists use to represent them. So the medium carrying information conforms to mathematical laws, while the information itself has contradictions.

Matter obeys the dictates of math and physics, but symbols do not. It is only because biology has the ability to create symbols that it is able to generate negative information entropy and transform disorder into order (Walker et al., 2017). This invokes the possibility of wrong answers, which cannot be avoided. This is the very definition of induction, where you cannot prove whether an assertion is true or false.

This means that many physical systems can be mathematically modeled and many may be deterministic. But by definition, no system which can do induction can be reduced to mathematics. This is why we are unable to explain the origin of the genetic code or model the human mind, or precisely predict anything in the soft sciences, or precisely model the evolutionary process. It is not simply that these things are too complex; it is that they are not computational processes. Thus no complete mathematical model is possible. This may help to explain why, as Shapiro says, "We lack a detailed account of any major evolutionary transition. The origin of life is the most obvious example, but we have similarly sketchy accounts of how the first cells came to be, of how cells evolved complex structures like nuclei and mitochondria, of how multicellular organisms arose, and of how complex organs like the brain and the immune system evolved." (Shapiro, 2011).

Nevertheless, biology has fallen prey to "physics envy", insisting that biology is just sophisticated physics and chemistry (Nelson and Richard, 2015). If that is true, we have a great deal yet to learn about both physics and chemistry. Richard Feynman famously said, "That which I cannot build I do not understand" (Feynman, 1985). If that is true, then the gold standard in science should not be peer review, but engineering: Can you build it, and does it work? Just because we can't model these things doesn't mean we can't build them. An engineering solution to Origin of Life and Evolution would also answer the following questions: How do we build a cell? How can we build synthetic devices rivaling the capabilities of a cell? How might we design a car or plane or appliance that self-repairs and self-evolves? How can we regenerate organs and reverse aging?

7. Biological information and the OSI 7 layer model

Marshall and Rinaldi (2004) and Spurgeon (2000) explain that the OSI 7-layer model in computer science says the lowest layer of any communication is the "physical layer": copper, fiber, magnetic tape or radio wave. Higher layers add levels of abstraction, for example: how states like "0" or "1" are represented as voltage on the wire or pulses of light on fiber; symbols like ASCII characters; and on up the chain through various levels of network protocols, operating systems, spreadsheets and web browsers. Information is always encoded "top down" and decoded in the exact reverse order. What is implied though not always stated is that there is always a cognitive (human) agent at the top of the stack (see Fig. 1). Thus communication in practice is always a cognitive phenomenon and not exclusively mechanical.

This reflects the fundamental nature of nested information structures. The genetic code also follows this structure, with DNA/RNA molecules as the physical layer, codons the next layer, instructions to assemble amino acids into proteins above that (Marshall, 2021). I propose that, just as with technology, agency is orchestrating biology. Numerous sources show that All living cells are cognitive (McClintock 1984; Margulis 1971; Levin 2022; Ginsburg and Jablonka 2019; Baluška et al. 2021; Noble 2016; Torday 2023; Liu 2022; Heng 2019; Laukien 2021; Baluška and Yokawa, 2021) and not only do genetic instructions build the cell, the cell alters its own genetics in response to environmental challenges.

To suggest that accidental insults to the DNA molecule supply the raw material for evolution (as advocated by Coyne (2009), also see Noble's "Illusions of the Modern Synthesis" (Noble, 2021) is like saying that one can improve phone calls by running an arc welder next to a telephone line. Both produce information entropy (Marshall, 2015; Shannon, 1948) thus it is not possible for this to be true. This is reinforced by the fact that cells possess extensive error detection and

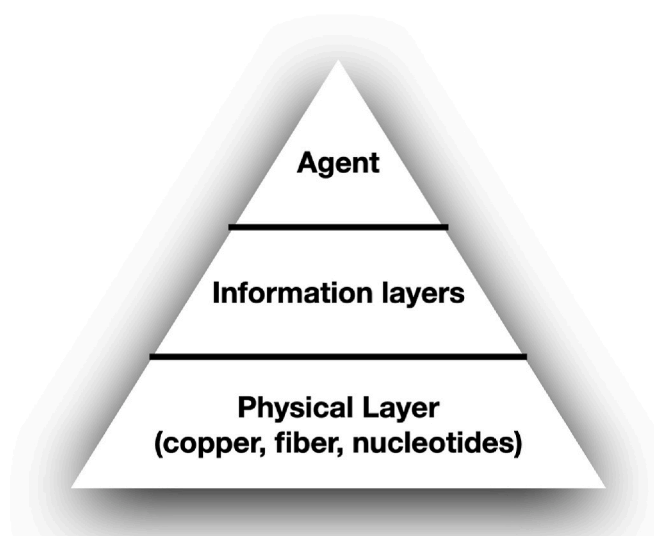

Fig. 1. The agent in relation to the OSI 7-layer model.

correction systems (Shapiro, 2021). McClintock (1953) discovered that when she damaged DNA with mutagens (and her experiment *was* analogous to running an arc welder next to an Ethernet cable), the corn plant activated transposons to repair the damage. When confronted with hostile circumstances, the organism engineered a novel solution to damage that had never occurred before. A corn plant engaged in inductive reasoning. This leads to the conclusion that top down causation is a major feature in biology, just as it is in engineering. Causation is not exclusively top-down nor bottom-up, but a continuous set of feedbacks which together make the 'organized whole' which expressly characterizes the seamless, intentional macroorganism, i.e. there is no privileged level of causation.

8. Questioning the standard description of causation as chemicals - > code - > cognition

We can investigate whether this is true by asking where code comes from. Yockey (2005) framed this question in terms of Claude Shannon's 1948 paper "A Mathematical Theory of Communication" which defines communication as a message passed between an encoder and decoder, subject to noise (information entropy). Yockey said "There is nothing in the physico-chemical world that remotely resembles reactions being determined by sequence and codes between sequences … There is no trace of messages determining the results of chemical reactions in inanimate matter … The origin of a genetic code is a bridge that must be crossed to pass over the abyss that separates chemistry and physics from biology … The existence of a genome and the genetic code divides living organisms from inanimate matter." Yockey showed in the same text that DNA transcription and translation is isomorphic with both Shannon communication systems and Turing machines. This means we can apply Turing mathematics to resolve one of the most long-standing puzzles in biology.

Only an agent *wants* to find an answer. The computer itself does not want anything. Only an agent wishes to know whether the bee will find pollen or whether the bird will find a worm. The capacity to ask such questions is inductive and cannot be posed by a computational device not already programmed to do so. Thus biology cannot be reduced to mathematics. Even Mathematics cannot be reduced to mathematics; that is the essence of Gödel's incompleteness theorem.

Similar proofs have also been published by Kauffman and Roli (2021), Louie (2020), and Rosen (1991), who used different approaches to arrive at the same conclusion. Kauffman applied set theory to affordances; Louie approached the problem through relational biology; Rosen said living systems are capable of anticipating future events and adapting to them, whereas computational systems are fundamentally reactive and can only respond to inputs based on predetermined algorithms. This can also be stated in mathematical terms: The axioms of any mathematical system cannot be computed or derived from the system itself; they must be chosen (Marshall, 2021; Weyl, 2013).

In the halting problem, this also requires the agent to have the ability to perceive the inputs and outputs of the Turing machine and form an expectation of what will happen in the future. This requires memory, awareness of the future, and imagination. Compare this to Shettleworth (2009) who defined biological cognition as "the mechanisms by which animals acquire, process, store, and act on information from the environment. These include perception, learning, memory, and decision making."

Any decision regarding the future is induction. Strictly speaking, it is impossible to deduce what will happen. We cannot deduce that the sun will come up tomorrow morning, we can only infer. Induction regarding the past refers to our inability to *know* exactly what happened. We infer from lots of data that Plato was a real person.

An abundance of basal cognition and Third Way Evolution research shows beyond any doubt that cells, tissues and organisms have cognitive abilities. "Even single bacterial or archaeal cells are endowed with life-specific characteristics and features to such an extent as to be properly deemed as having a basal form of proto-consciousness as well as intentional and cognitive capacities." (Baluška et al., 2021). This includes "sensing the environment (e.g. epigenetics and initiation of hypermutation), interpreting the meaning of signals (e.g. DNA linguistics, repair and checkpoints), making decisions (e.g. transposition events), taking action based on self-interest (e.g. self/non-self identification; resistance to cancer therapies), and modifying themselves (e.g. genome chaos and hypermutation)" (Marshall, 2021).

Therefore while much activity in biology *is* classical physics and chemistry with algorithmic responses, the mechanism that causes the organism to make novel adaptations is not. In Barbara McClintock's Nobel Prize paper (McClintock 1984), she distinguished between threats like heat shock and starvation, for which cells have an algorithmic response, in contrast to threats for which there is no precedent. Novel threats result in unpredictable, contextual responses. McClintock was the first modern biologist to ask that future research "determine the extent of knowledge the cell has of itself, and how it utilizes this knowledge in a "thoughtful" manner when challenged" (Shapiro, 2014).

Levin reports that tadpoles were placed in a solution of barium, which is a non-specific blocker of all potassium channels. This made it impossible for the neural tissues in the head to maintain normal physiology, and as a result, the tadpoles' heads exploded. However, the experiment showed that the flatworms soon regenerate a new head which is barium-insensitive. The experimenters had no reason to believe that the tadpoles' ancestors had already learned this protective response; it's possible that this was the first time this had ever been done in history. It shows that organisms engineer novel solutions to unique problems in real time (Levin, 2022).

Information is generated by cognition. It is mathematically impossible for the opposite to be true. We are left with the central question of biology: What is the nature and source of cognition? This leads us to the double slit experiment.

9. Biology and the double slit experiment

The venerable double slit experiment (Davies, 2019; Greene, 1999), now 200 years old, shows that cause and effect do not conform to our classical intuitions. A coherent light source pointed at a screen and blocked by two slits will produce an interference wave pattern on the screen. This holds true even if the photons are fired at the screen one at a time.

However, if one puts a particle detector on one slit to see which slit the particle passed through, it ceases to produce a wave pattern. It makes a dot on the screen instead.

Then if one unplugs the particle detector, the system produces a wave pattern again.

It is as though the particle "knows" whether the experimenter is looking for a particle or a wave. It even "knows" whether the detector is working or not.

Before the measurement is made, the particle exists in a superposition of orthogonal states: It is both particle and wave. Once the measurement is made, the superposition collapses to a basis that is determined by the nature of the measurement and the measurement device. If this basis is a property of the particle nature of matter, a particle is observed. If this basis is a property of the wave nature of matter, a wave is observed.

10. The principle behind wave collapse in quantum mechanics

Nobel Prize winner Anton Zeilinger said the following about quantum superposition:

> "[T]he superposition of amplitudes … is only valid if there is no way to know, even in principle, which path the particle took. It is important to realize that this does not imply that an observer actually takes note of what happens. It is sufficient to destroy the interference

> pattern, if the path information is accessible in principle from the experiment or even if it is dispersed in the environment and beyond any technical possibility to be recovered, but in principle still "out there." The absence of any such information is the essential criterion for quantum interference to appear. (Zeilinger 1999)

This is strange. Physicists have struggled to explain it for 100 years (Heisenberg 1958). But even in the very short description given above, a vital observation must be made: *The quantum system behaves as a whole, not as merely the sum of its parts.* This is precisely what is so strange about it. It may appear to just be an assemblage of parts: a screen, a laser, two slits, a particle detector, cables and LEDs. But the behavior of the particle is determined by the macro configuration of the entire system.

11. Interpretations of QM

Some but not all interpretations of QM say the observer plays an active role in the outcome of the experiment. Two that do are the Copenhagen Interpretation (Bohr 1928; Wigner 1961; Everett 1957; Bohm 1952) I am most sympathetic to the Consciousness ("Von Neumann-Wigner") Interpretation of QM (von Neumann 1932; Wigner 1961), which extends the Copenhagen Interpretation by proposing that an observer's consciousness is required for wave function collapse to occur. This suggests that the physical process of measurement is not enough to cause the collapse; instead, it is the observer's conscious awareness of the result that leads to a definite outcome.

It is unclear whether it is the conscious awareness of the observer collapses the wave, or if it is merely the conscious action of an observer that was required to build and operate the detector, so a measurement could be made in the first place. The evidence we do have shows that, so far as we know, *acts of measurement do not exist outside of biology.* This is because symbolic information does not exist outside of biology (Walker et al, 2017). Only cognitive agents build particle detectors, Turing machines or Shannon communication systems (Marshall 2015, 2021; Yockey 2005). This question reaches all the way back to the origin of life itself. This is a crucial point: either way, wave collapse is always associated with cognition with no documented exceptions. QM and biology are driven by choices, in contrast to the classical world which runs on fixed laws.

12. QM in biological processes

A growing vein of literature shows that multiple biological processes cannot be fully explained without invoking QM. These include phenomena such as enzyme catalysis, photosynthesis, and olfaction (Ball, 2011; McFadden and Al-Khalili, 2018). Davies (2019) discusses exciton behavior in a photosynthesis experiment by Engel et al. (2007): "Viewed in terms of pathways, there are many routes the exciton can take and, if quantum coherence is maintained, will take - simultaneously. Loosely speaking, the exciton is able to sift all the options at once and feel out the best possible route to the reaction centre. And then take it. What I am describing is an extraordinary type of [Maxwell's] demon, a quantum super-demon that 'knows' all available pathways at once and can pick the winning one." *The exciton's behavior is a sterling example of inductive reasoning.* The superposition state is the means by which organisms consider multiple future paths. Wave collapse is when they act to create order from chaos - *without violating the laws of physics.*

Macro also determines micro. The whole controls the parts, in addition to the parts controlling the whole. The mere *availability* of information determines the outcome. Which is precisely the problem that biologists have struggled with for 100 years. How does a whole organism maintain itself and alter its individual parts to maintain homeostasis and evolve?

13. Radin's double slit experiment

Dean Radin conducted an experiment (Radin et al., 2012) which sheds further light on this. Radin asked whether trained meditators could influence the outcome of the double-slit experiment. He aimed to test if conscious observation by experienced meditators could influence this wave-particle duality. Participants, which included both trained meditators and non-meditators, were asked to direct their attention towards the double-slit apparatus and attempt to mentally "collapse" the wave function, forcing the particles to behave like particles rather than waves. The study reported that, during periods when meditators were focusing their attention on the double-slit apparatus, there was a statistically significant shift in the interference pattern compared to the control group of non-meditators. It would be worthwhile to conduct this experiment with a much larger number of subjects.

This result suggested that the meditators' conscious attention might have influenced the behavior of the particles, causing them to exhibit particle-like behavior. This experiment showed a confidence of 4.36 sigma and p value of 6·10ˆ-6. While not definitively proving a causal relationship, it strongly suggests that the intent of the observer is a deciding factor in the outcome of the wave collapse. Radin's experiment implies wave collapse is caused by the act of observation. Or it might be caused by the prior effort to detect it. It is beyond the scope of this paper to decide between these two; the point is that, either way, an agent must exercise intent. The superposition collapses to either particle or wave as a result of a cognitive agent doing inductive reasoning.

14. Hypothesis: biology exercises agency through wave collapse

When combined with what we know about basal cognition and Cognition-Based Evolution, the double slit experiment doesn't seem quite so strange after all. It coheres with what we know about observers and measurement. All cells measure information (Reber et al., 2023; Miller, 2018). Lyon (2015) categorizes bacterial cognition as sense perception, discrimination, memory, learning, problem solving, communication, motivation, anticipation, awareness, self-reference, normatively and intentionality (Fitch, 2008). The role of an observer in the double slit experiment involves identical categories of cognition in order to participate in the experiment, detect and record outcomes. The organism must prioritize inputs and actions which is called *valence*. "Valence refers to the attractiveness, acceptability or tolerability of a stimulus … the valence of a signal is implicit in the processes that coordinate, say, the rotation bias of flagellar motors or the complex developmental sequence of signaling, genetic transcription and protein expression that leads to sporulation" (Lyon, 2015) (See Table 1).

Thus I propose that measurement in a cell and measurement in the double slit experiment are the same thing. When a cell evaluates salinity, light sources, food sources, predators or viruses, it must generate and interpret symbolic information which is by nature incomplete (Miller, 2018). There is no such thing as a measurement without a measurer. Measurement according to the definition in Table 2 requires code which is exclusive to biology.

15. What is an observer?

This raises several questions: What is an observer? What is a detector? What precisely does it mean to make a measurement? Fields (2012) says, "The physical structure of an observer is rarely addressed." It is

Table 1
Equivalencies between biology and QM.

Biology	Quantum Mechanics
Cognition	Observer
Code	Detector
Chemistry	Wave Function Collapse

Table 2
Definitions.

These definitions are compatible standard dictionary definitions and usage, but worded specifically for this paper so as to be mutually compatible and elucidate the hypothesis that is being advanced.
Cognition: Ability to do inductive reasoning. Cognition is isomorphic with observers in QM, choices, evolution, measurement and perception, harnessing stochasticity, inductive reasoning, assigning meaning to symbols, axioms in mathematics, formulation of scientific laws, negentropy and Maxwell's demon (Marshall, 2021).
Code: Symbols exchanged in a Shannon communication system, which is also a Turing Machine (Yockey, 2005). Code is isomorphic with particle detectors, computers, algorithms, Turing Machines, Shannon communication systems, DNA-RNA transcription and translation, deductive reasoning, mathematical functions, symbols and logic (Marshall, 2021).
Chemistry: Physico-chemical laws of classical physics and chemistry, "particles and waves," and outcomes of wave function collapse. The distinctions between Cognition and Codes and Chemistry are sharp, with only a narrow band of ambiguity between them, as follows: The dotted line between cognition and codes is the space between induction and deduction. This is Turing's halting problem. All knowledge about any externally measured event starts as inductive and only becomes deductive once a successful symbolic model of that process has been constructed by the agent. All cells and all living things do this. Turing's halting problem and Gödel's incompleteness theorem say that computational devices can only reason deductively, cannot make choices, cannot generate axioms that were not already in place; cannot generate or prove their own assumptions. Inductive reasoning is any time an agent predicts what will happen in the future in absence of the ability to compute it. Induction is anytime you are predicting if, when, where, why, or how the machine will halt. The 'dotted line' between codes and chemicals contains an ambiguity. It is the question of whether any physical state is a symbol or not. Symbols only exist in a context of encoding and decoding. A symbolic relationship can only be confirmed by Mutual Observation of Physical Event, see definition below.
Observer: Cognitive agent capable of inductive reasoning and capable of externally communicating its expectation of whether the Turing machine will halt.
Detector: A Turing Machine/Shannon Communication system capable of sensing a particle and storing symbolic information about the particle's status. A detector does not have cognition.
Inductive reasoning: Any reasoning that is not deductive (Marshall, 2021). Induction is any time an agent makes a guess about the future which cannot be calculated (Turing's halting problem). Only a cognitive agent (subject, observer) asks whether a Turing machine will halt, because only a cognitive agent has conscious awareness of time. A Turing machine cannot ask itself whether it will halt, it can only obey instructions. This is the boundary between the explicate and implicate.
Deductive reasoning: Symbolic logic; computation via mathematical functions or Turing machines. ("General recursive function - Encyclopedia of Mathematics," n. d.) According to the Church-Turing thesis, the two are equivalent (Church, 1936). I accept the Church-Turing thesis and take it as axiomatic in this paper.
Measurement: Recording classical Shannon information about whether quanta collapsed to a particle or a wave, or any other physical event. The act of measurement makes the wave function collapse. "Measurement" means the same thing in QM as in cell biology.
Collapse the Wave Function: When a quantum system transitions from being in a superposition of multiple states to a single, definite state upon measurement; i.e. conduct the double slit experiment and observe an outcome that is either a classical particle or a wave (Greene, 1999). Also known as decoherence. (Note that there are some interpretations of QM that say that the wave function doesn't actually collapse. Deciding between these views is beyond the scope of this paper and I am using the most common language employed to describe the double slit experiment.)
Symbol: A mapping from Set "A" to Set "B" where the word "set" is used in the abstract mathematical sense. (Yockey, 2005) In DNA, GGG maps to Glycine. In HTML, maps to "Bold." In a traffic light, "red" maps to STOP.
Information: Symbols exchanged between an encoder and decoder (Shannon, 1948). Information is a physical representation of a choice, which is measured in bits (and not kilograms, meters, seconds or other physical quantities).
Physical Event: A classical outcome that was measured and recorded above the Landauer limit, and which an observer has enough bits of Shannon information to provide adequate context to confirm the existence of that event. (Fields, 2012; Levin, 2020).
Meaning: When both encoder and decoder share a common definition of a symbol. (In cells, GGG means Glycine. AAA means Lysine. In ASCII, 1000001 means "a".)
Mutual Observation of Physical Event: Two or more observers share enough classical information and context to agree on the meaning: The event actually happened; both are symbolically referring to the same event in their communication with each other, and both agree that it occurred. (This relates to the Qualia problem.)
Qualia: The fact that we cannot know what it is like to be another observer. "I can't know whether you experience red the same way I do." We can only know what the observer tells us about his measurements. (This also means that the relationship between two observers is always inductive and subjective.) (Chalmers, 1995; Nagel, 1974).

hardly obvious why a particle detector collapses a wave, while the gas in the room or the table the experiment is on does not. Fields explains this by employing a model where an observer must be an information coding device with the ability to store classical information (not quantum) above the Landauer limit, which is the minimum amount of energy necessary to store a bit of information. He says, "Such a virtual machine may be implemented as software on any Turing-equivalent functional architecture."

In other words, in order to collapse a wave function, the observer must record the event using the equivalent of a computer or Turing machine. Since cellular machinery that conducts DNA/RNA transcription and translation is a Turing machine (Yockey, 2005), and since all cells possess cognition, this means a cell has the means to collapse the wave function *and make a physical record of the event.* There are several ways organisms store information in memory, including long-term memory storage through chemical and electrical signals, RNA, DNA reverse transcription, epigenetics and bioelectric substrates (Blackiston et al., 2015).

It's natural to ask, "Why don't the bacteria in the air collapse the wave function?" I hypothesize that bacteria can collapse a wave function if the outcome is relevant to their survival. This would make their observational capacities a part of the quantum system. This is discussed further down.

It is also significant that Turing machines, Shannon communication systems and particle detectors (all of which are isomorphic) only exist in the realm of biology (Marshall, 2015, 2021; Walker et al., 2017; Yockey, 2005). They are either present in cells or designed by humans. They do not exist in the purely physico-chemical world.

Levin and Fields say:

> "At the level of molecular interactions at the Angstrom, femtosecond scale of molecular dynamics calculations (Vlachakis et al., 2014; Zwier and Chong, 2010), biological systems are quantum systems, and biological information processing is quantum computation: cellular energy budgets of both prokaryotes and eukaryotes fall orders of magnitude short of the power required to maintain classical states of just protein conformation and localization at this scale (Fields and Levin, 2022), despite the massive consumption of ATP by big-brained eukaryotes such as humans (Okuno et al., 2011; Ueno et al., 2005). Hence cellular information processing cannot be entirely, or even primarily classical …"

Fields notes that for two observers to agree on the results of a physical event, they have to share enough mutual information to be certain they are referencing the same event. If the event is the collapse of the wave function, not only does each need to know "0 = particle, 1 = wave", they also need contextual data: Which space they were in, surrounding objects, what time it was.

16. Contextual nature of information

No code can exist without a context of encoder and decoder, which is why both encoding and decoding tables must be able to be drawn (Shannon, 1948). Likewise, no two agents can agree on the meaning of any code unless they both possess the same tables. So not only must the message transmit information, multiple recipients also require mutual context information. (Fields, 2012) The context problem is the qualia problem: It is impossible to know firsthand the experience of a conscious observer (Nagel, 1974). There is no way to know whether you and I experience "red" the same way. The best we can do is share information about it. The more information we share about the red house, the red car, the red scab on my knee, the more confident we are that we are both seeing the same color.

This speaks to the boundary between chemicals and code: It's not possible to determine a sequence of nucleotides or 1s and 0s or pulses of light is a code until sufficient context is established above a minimum information threshold.

A series of equivalencies unifies biology and QM, as defined below:

With the above definitions in place, we can explore how this unifies many streams of thought in science. Fig. 2 illustrates the flow of cause and effect in a cell as it both receives information and acts on its environment:

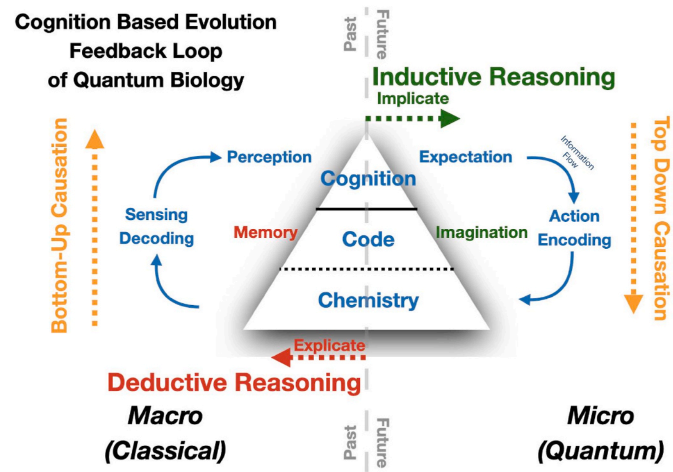

Fig. 2. Caption: All organisms have memory and anticipate the future. The vertical line running down the center divides the future (right) from the past (left). The picture is two dimensional, with the X-axis representing time and the Y-axis representing flow of information between cognition which is quantum, and the physical world which is classical. The pyramid, based on the OSI 7-layer model from computer science, shows cognition at the top, layers of code in the middle, and the physical layer at the bottom, labeled "chemistry." It shows the flow of information. Predicting the future is induction. Effects of decisions made in the present flow deductively into the past. All cell action is communication (Miller et al., (a) in press). At the quantum level, the cognitive agent collapses a wave by the act of observation. Wave collapse triggers a physical change in the system above the Landauer limit. This enacts macro changes in the environment which are recorded as past events. Those changes are sensed, encoded into symbols and perceived by the agent. The feedback loop of expectation and perception runs clockwise. The solid line between cognition and code represents the sharp boundary between deductive and inductive reasoning. The dotted line between code and chemicals represents the inability to be absolutely certain of the meaning of any physical symbol. Between the organism and its environment, this is the problem of perception. Between two agents, this is qualia. Causation in the quantum world is top-down, while causation in the classical world is bottom-up.

17. Wave collapse is communication

At the macro level, when we operate a computer, a person types on a keyboard. The keystrokes are physical actions by the person's fingers, but they are first and foremost symbols, because the human has chosen whether to type "A" or "S" or "D" or "F" on the keyboard. Those keystrokes are written (encoded) into a physical medium (signals on copper or fiber, hard drive, USB stick, SD card etc.) and then read (decoded) in reverse order. The letters appear on the screen and the agent checks to see whether the screen says what he or she intended.

A traditional computer not being operated by humans, running a preloaded program, is a classical and deductive device. Its physical operation is entirely "bottom up." However, the computer can only be understood or programmed from a top-down point of view. As Michael Levin says, when you want to move a file from the desktop to the trash, you don't do it with a soldering iron.

Miller says, "everything a cell does is a form of communication." (Miller et al., (a) in press) Any information processing by a cell initiates a thermodynamic work channel that becomes potential communication to some other observer in the same information space. This is key to understanding the causal diagram above. An agent causes wave collapse which is a physical ("chemical") change. However, this action is first and foremost a communication signal. So by mechanisms still not understood, the observer, by intention, biases the superposition state to collapse to a desired physical event. Miller recognizes that all knowledge that a cell has about what is outside its cell wall is necessarily incomplete (Miller et al. (b) in press), so the organism is making approximations as to what is outside. This is induction.

18. Scale independent cognition

The diagram in Fig. 2 is fractal, or scale-independent. It describes the feedback loop between action and perception, not just on the cellular level but macro as well – tissues and multicellular organisms. At the micro level, I hypothesize that the cognitive intent of a cellular whole causes a superposition of states to collapse to a classical physical event. This initiates a chain of actions (such as opening or closing ion channels) which control classical-level systems in the cell and macro systems in the organism (Kapuy et al., 2009; Tyson and Novak, 2014).

Ion channels are subject to quantum mechanical effects. Quantum mechanical tunneling has been observed in synaptic and enhaptic transmission (Walker, 1977). The ability of the observer to choose actuals from possible states is the mechanism by which agency and free will are possible (Kauffman and Radin, 2023).

Davies says, "Why do the laws of physics come with informational capabilities beyond anything that Shannon imagined, if nature hasn't made use of it anywhere in the universe?" He goes on to say, "… as a theoretical physicist I have found that if well-established physical theory predicts that something is possible, then nature invariably seems to make use of it." If we posit that all cells are cognitive and, as demonstrated in photosynthesis, have the ability to explore possibilities in quantum space before expending resources to implement them physically, then we can begin to envision how mechanisms for high speed evolution (such as those described by Levin, Shapiro, McClintock, Margulis, Torday and Noble) can operate with hitherto unexplained effectiveness.

19. Discussion

This Cognitive Interpretation of Quantum Mechanics, as described above, leads to two hypotheses:

1. A new double slit experiment can be designed to show that not only can a human be an observer, but so can a cat, dog, goldfish or amoeba.

A dog can interact with a particle detector much as a person can. If it's a particle, the dog gets steak. If it's a wave the dog gets spinach. The experimenter randomizes the relationship between wave collapse (particle vs. wave) and which food the dog receives. Assuming 100% of dogs prefer steak over spinach, the experiment might show that 51% of the time the dogs got steak, and 49% of the time the dogs got spinach, with statistical significance. This must be run against an experiment where a randomizer was present without a double slit apparatus, and the results compared.

"Dog gets treat if it collapses a wave function" is a variant of Radin's experiment. Radin asked his subjects to desire for a wave and got a wave a statistically significant percentage of the time. The experimenter has to design an experiment so the animal prefers outcome A over outcome B, randomizing the trials so the mechanism is not the same every time.

If Zeilinger is correct and the mere existence of an available information path is enough to collapse the wave function, then randomly changing available information paths and recording them for later reference should lead to dogs or goldfish or amoebas caring about, and influencing, the outcome of a double slit experiment. It is easy to find hypothetical discussions online about whether animals can collapse wave functions, but the literature does not report any such actual investigation. This has the potential to be a landmark experiment. It may take clever execution to make work. I propose we can re-run the same experiment for goldfish or dragonflies or prokaryotes and infer that they are conscious as well. The experiment may prove easier to conduct with insects and microorganisms than with people or animals.

2. Cells, by virtue of possessing agency, cognition and Turing equivalent architectures, act on the external world by collapsing the wave function. By directing their attention (valence) and collapsing, at will, a superposition of possible states, organisms make choices in the exact manner of Maxwell's demon. This is how they initiate communication, harness stochasticity, generate negentropy, and evolve.

I hypothesize that what collapses a wave function is induction, which must be exercised to a) build any particle detector or Turing machine, and b) sense the external world and record a measurement. This supports my chosen definition of observer as a "Cognitive agent capable of inductive reasoning and capable of externally communicating its expectation of whether the Turing machine will halt."

If this is the case, it further supports the viewpoint that the reductionist perspective has misinterpreted causation, and that consciousness is essential to the fabric of reality rather than being an emergent property or epiphenomenon.

20. Wave function collapse and first principles of physiology

Torday proposes an origin of the first principles of physiology as follows: "Gravity caused the vertical alignment of lipid molecules at the water-atmosphere interface. The negative charge of the lipids in water neutralized the Van Der Waals force for surface tension, causing a phase transition/Quantum Leap from lipid molecules to micelles. Gravity imparted the energy needed for Quantum Entanglement of particles entering the cell, allowing for negentropy. That constitutes "local" consciousness, with reference to the non-local consciousness of the Cosmos. The local and non-local consciousness are held in balance by homeostasis" (Torday, 2023).

He is suggesting that the first cell began not as a self replicating RNA but a micelle with particle entanglement powered by gravity impinging on the curved surface, making the micelle, in the language of this paper, an observer. This is a metabolism or lipid first argument rather than an RNA first argument. He goes on to propose that the first memory, necessary to maintain homeostasis, was epigenetic. This would explain why the genetic code was developed by the first cell: To provide the cell with a means for extending memory.

In physics, there has been much resistance to the idea that there is something special about mind, cognition, consciousness and observers. In biology, there is a similar resistance to the proposal that there is something special about life. But the problems remain unsolved. If we define cognition as inductive reasoning; codes as computing; and chemistry as physico-chemical laws; it becomes clear that reductionist models by definition can never solve these problems.

Thus mind and life are indeed special. We still have yet to discover this unknown principle or "law of physics" that explains the nature and source of cognition. But now parallels between cellular information processing and QM suggest the answer may be found within the structure of its quantum apparatus. It should be feasible to observe the phenomenon closely enough to reveal the underlying events. Biology's systems for orchestrating the transformation from order to disorder remain an enigma, but it consistently performs its task, ready for us to uncover its secrets. This promises to be one of the greatest discoveries in the history of science, on par with QM itself, relativity, the invention of the transistor and the discovery of the DNA helix.

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Perry Marshall: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization, Project administration, Funding acquisition.

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