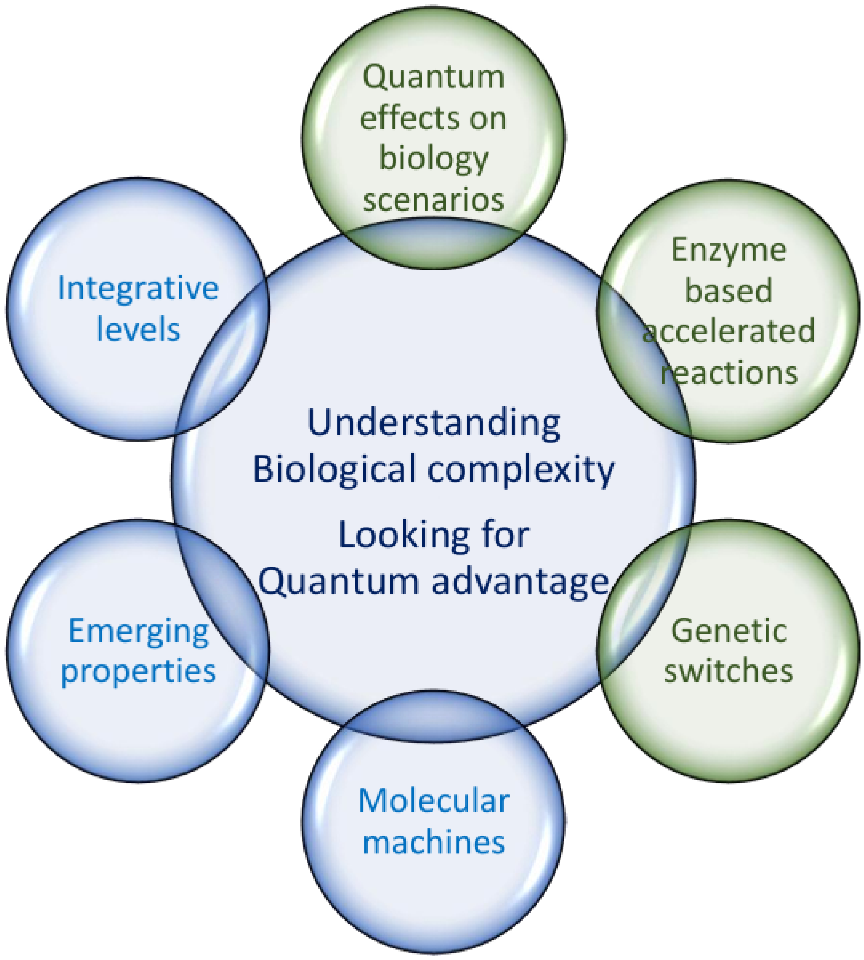

Figure 1: Understanding Biological Complexity

1. Introduction

Quantum phenomena are all around us and affect every scale; however, they may not be easily detectable in larger objects. Quantum discoveries are being incorporated into our foundational understanding of materials, chemistry, biology, and astronomy.

Quantum science bridges gaps in our understanding of physics, providing a more comprehensive picture of our everyday lives. Quantum physics focuses on matter and energy at the most fundamental level by uncovering the properties of the very building blocks of nature [1]. Quantum chemistry can explain the behaviour of atoms and molecules using the principles of quantum mechanics. It dives deeper into the world of electrons, protons, and energy levels. Quantum biology is the study of applying quantum mechanics and theoretical chemistry to aspects of biology that classical laws of physics cannot accurately describe. # 2. Modern science: where do we stand? The book "Science Delusion", by Rupert Sheldrake, lists ten assumptions that align with the worldview held by almost all educated people worldwide. He strongly questioned the infallibility of these assumptions, successfully identified loopholes, and labelled them as dogmas. These ten dogmas or assumptions are - 1) The universe (nature) is like a machine; it includes all animals and plants 2) The whole universe is made up of unconscious matter 3) Laws of nature and constants are fixed, the same as they were at the time of the Big Bang
4) The total amount of matter and energy is always the same 5) There is no purpose in all nature, and

the evolutionary process has no direction 6) What we inherit as heredity is material (genes, epigenetic modifications, or cytoplasmic) 7) Memories are stored inside your brain as material traces 8) Your mind is inside your head - all your consciousness is the activity of your brain. 9) Psychic phenomena like telepathy are impossible 10) Mechanistic medicine only works- the rest is a placebo effect or a natural healing

Rupert's arguments are strong, a little bit overboard. However, they may be seen as indicators that we are still in the initial stretch and have a long way to go to unravel nature.

Need for new conceptual lenses and frameworks in science?

Our modern society has become overly enamoured with the latest scientific breakthroughs, dismissing traditional forms of knowledge and wisdom that have been passed down through generations. Our current approach to science assumes that great ideas only come from the most advanced and cutting-edge research centers. Human intelligence has not suddenly spiked since the 19th century, and there is much to be gained by reconnecting with the wisdom and practices of our ancestors. It is time for us to recognize the value of traditional sciences and embrace the lessons they have to offer.

The verticalization existing in basic sciences (mathematics, physics, chemistry, and biology) is not 'natural'. Maths dealing with abstract relationships may not be directly connected to the physical world, while the objective of physics is to unravel fundamental principles/ laws that explain natural phenomena, matter, and their properties. Chemistry focuses on what constitutes matter and how the macroscopic world is impacted. Biology is more into how life processes and systems work. It may consider living organisms at multiple scales, ranging from the molecular level (biochemistry), the structure of organs and parts (physiology), at a larger systemic level in space (ecology), and time (evolution).

Science must develop to a stage where it can explain the complexities of the social sciences. Thus, perhaps we have not yet reached the right stage of our scientific journey to understand 'Fundamental'.

Mathematical treatment of biological research

The mathematical application in biological research follows two paths. First, quantitative form; second, analysis of relationships observed in living systems, both following deterministic and statistical treatment. Mathematics has emerged as quite popular in biophysics, taxonomic problems, epidemiology, genetics, etc.

Hardy and Weinberg, in 1908, introduced the concept of allelic equilibrium suited for a panmictic population (unrestricted interbreeding) and founded population genetics. They propounded a principle of biological inertia that helps to calculate the frequency of heterozygous and homozygous genotypes. It also helps to explain microevolution. The synthetic theory of evolution, which grounds evolutionary biology by combining Mendel's synthesis and Darwin's biometric approach, owes a lot to mathematical models connecting evolution and genetics (Forestiero, 2022) [6b].

Biological research focusing on biological subsystems using a reductionist approach, quantitative treatment, and descriptive/predictive purposes is common. The focus on the qualitative and relational aspects is convincingly explained using topology (geometry). However, the modelling of species evolution and ontogenesis remains elusive. # 3. Biological complexity, origin, and evolution of life From a mix of naive realism and emergentist perspectives, it is natural to ponder: Is there an inherent tendency in the cosmos where the smaller units combine to evolve into bigger and complex systems? During the time of association, the constituents may lose their characteristic and behave differently. The resulting system may also fall into the definition of a living system, where constituents are replaced, but the association, together with its uniqueness, continues. The association grows strong, matures, and weakens over time (lifetime) and then dissociates into constituents. The sense of association (identity) becomes supreme and surpasses the mere physical form [2]. The cells, tissues, organs, and organisms are sites where "non-living" substances assemble as per the genetic code, perform some function as a part of that system, and then disintegrate again into the "non-living" entity. This is a simplistic philosophy on living systems.

Schrodinger's insight into - What is life?

Ervin Schrodinger's book, "What is Life?", published in 1944, applies a scientific approach to exploring life (biological systems) by investigating underlying fundamental principles of physics and chemistry [3]. The author has first investigated 'why are atoms so small'. The behaviour of an atom changes from a disorderly manner to an orderly manner as it joins together with other countless atoms and molecules, forming a complex structure in the human body. The large size of the biological systems vis-a-vis an atom contributes to their coherent functioning. An individual gene, a specific DNA segment, can be viewed as a relatively small conglomerate of atoms. Schrodinger investigated the crucial role of genetic information encoded in the sequence/arrangement of nucleotides along the strand of DNA. The orderliness observed over a long time in the DNA molecules is surprising and can be attributed to aperiodic crystals that also encode biological information.

The orderliness in living systems, both at small and large scales, is contrary to the disorder/decay into a thermodynamic equilibrium state, observed in inanimate systems. Schrodinger speculated that the stability, storage fidelity, and replication of genetic information could arise from quantum tunnelling and quantum coherence. Living systems successfully counteract this tendency while maintaining a high complexity and order by extracting energy from the ecosystem (offsetting entropy), for instance, metabolism in animals and photosynthesis [4]. A dynamic bouquet of metabolism, adaptation, and self-replication principles drives living systems. It is not classical physics that contributed significantly to modern biology; it is quantum physics that kick-started it off.

Biological complexity

Warren Weaver proposed three broad types of complexity: organized simplicity, disorganized complexity, and organized complexity. The organized complexity is characterized by classical physics laws at the particle level, and disorganized complexity is characterized by statistical mechanics (thermodynamics), along with probability theory at the particle level [5]. Organized complexity is akin to living systems, where the relationships among entities change with time, thereby enabling the acquisition of a form following organizational principles. The organizational principle, mostly seen at the mesoscopic scale, arises collectively from microscopic-level rules with almost no sign of dependence. Dynamical systems show the following aspects of complexity: (i) high complexity during their evolution; (ii) emergent properties appear from complexity without hiding macroscopic observables; (iii) spatial and temporal patterns beyond the topological dimension - need fractal dimension; (iv) nonlinear dynamics with sensitive effect of initial conditions (confusion of stochasticity); (v) existence of feedback processes. Bifurcation in dynamic systems follows symmetry-breaking. It leads to the emergent properties as a fallout of the amplification of microscopic fluctuations that may often lead to new configurations (new self-organization).

Is the complexity observed in inert (non-living) matter the same as that in living matter? Can mathematics explain the biological complexity, particularly the evolution of living organisms and ontogenesis? The answers to these interesting questions are mixed despite a few good attempts by Rashevsky (1954) [6], Rosen (1991) [6a], and Forestiero (2022) [6b]. The physical system complexity is driven by the transformation of physical entities at different space and time scales, while the living systems' evolution occurs by variation. A robust living system generally continues to function satisfactorily even in the event of mutations (internal noise) and environmental (external) perturbations. It may be attributed to the presence of multiple alternatives, but equivalent solutions - many genotypes produce one phenotype. Another possible explanation is that the source of robustness may lie in the evolutionary adaptation to perturbations.

Forestiero (2022) [6b] has drawn four basic features to identify complexity in biological systems, namely, individuality, organization, relationality (connection between the system and its components and environment), and diversity (byproduct of multiplicity and individuality). Complex systems, in general, exhibit nonlinear interactions among constituent components and emerging properties. While the physical complex system maintains the same properties, the biological system shows modifications over time.

The outcomes of biological research carried out in vitro vs those carried out in vivo show a large variation. This is unlike other natural sciences, where such simplification resulted in their rapid advancement. Thus, research on living systems in isolation from the environment is questionable.

4. Is quantum the fundamental?

The scientific reasoning can be categorised into deductive reasoning, inductive reasoning, and abductive reasoning. While inductive and abductive reasoning are used to form hypotheses and theories, deductive reasoning is used to apply theories to specific situations [7]. Despite having a well-established ecosystem for the development of scientific theories, there is a lack of robust theories of a general nature due to a lack of experimental evidence and support from the scientific community, etc. We are entering an era where abductive reasoning is gaining popularity [8]. There is a need to review the old age practice of treating a competing 'hypothesis' as a 'theory' merely based on overwhelming support by the greater scientific community, a unifying explanation, and providing that no testing experiment has turned out to be a failure.

The development of new theories is more influenced by the knowledge base available in the public domain, existing theories, supported by academia and the scientific community, etc. In this scenario, instead of expecting to see a rise of absolute theory (a perpetually true theory), it would be better to rate nascent theory by making use of Bayesian inference to update the probability for it to be true as more evidence or information becomes available.

Quantum theory relied more on abductive reasoning, where it used creative thinking and intuition to propose new conceptual frameworks for explaining phenomena not convincingly explained by classical physics. Subsequently, it utilizes the strengths of both deductive reasoning (predictions derived from established principles) and inductive reasoning (experiments used to confirm predictions).

Neil Bohr (1932) argued about the missing fundamental traits in the analysis of natural phenomena in order to adequately understand biological processes and systems based on physical experience. In the words of Max Delbruck, a German theoretical physicist, "a kind of missing trait that Bohr alluded to might be found by studying the physical and chemical nature of genetics - didn't mean that physics might help to explain genetics, but rather studying genetics might uncover some new principle of physics". It is noteworthy that during that time, nothing was known about the molecular origins of genetics. He established the idea of genetics as an information science [9].

If we go by the trends, it is too early to label quantum theory as the fundamental, in other words, the unified theory of everything. Hence, the expectation that quantum biology will become the fundamental tool to understand living systems in totality is also far-fetched. # 5. How does life work? From a perspective of quantum physics Scientists and technologists are using quantum effects to build advanced technologies. Unbounded imagination is growing common - Can cellular activities be controlled to treat disease using a cell phone? Genetic engineering and protein folding are better understood, and manipulation at small scales is picking up. However, it is still not well understood how quantum effects influence biological systems.

Quantum mechanics properties present a microscopic world that is pretty magical and counterintuitive. There is an increase in evidence regarding the use of quantum mechanics by biological systems to achieve optimal performance. Biological systems, with ambient temperature and noise, are supposedly the least likely place to observe quantum effects that are commonly observed at near absolute zero temperature, small distances, and mass. Classical mechanics is better placed to describe biology. In other words, "everything that starts quantum dies classical". However, Chemists attribute several short-lived, nanoscopic, quantum effects in biomolecular processes/materials (genetic materials and proteins) to macroscopic physiological processes as evidence. For instance, magnetic sensing, enzyme regulation, metabolic activities, and electron transportation in biomatter/molecules.

Research on how quantum effects tweak biological processes shall require appropriate tools that are capable of operating at a small length scale, a short time scale, and subtle variations in quantum states associated with physiological changes. Several physiological processes are influenced by weak magnetic fields (genetic material repair, cell proliferation, and stem cell development), as they change the electron spin and consequently the chemical reaction outcomes.

A few suggested biological physiological outcomes that can be mapped with potential quantum effects are as follows: - ? What magnetic frequency and strength cause specific chemical transformations in cells? ? Developing devices to produce weak magnetic fields to change physiological outcomes? ? Tweaking quantum properties to develop non-invasive therapeutic devices for preventing/ treating disease (brain tumour, food production)

In the rest of the section, three examples of potential quantum mechanical explanations of biological systems are presented.

Applying quantum mechanics to analyse biological scenarios

Photon absorption, photosynthesis, and the corresponding energy storage process use quantum effects. Penrose also tried to relate possible quantum processes in the brain. The FMO complex is a water-soluble pigment-protein complex. Its functioning (coherent assisted transport of excitations) at ambient temperature was significantly attributed to quantum coherence. However, a decade-long debate could not confirm it. Quantum effects are also held as the basis of the functioning of the Avian compass and sensing of odour.

The biophysical description of the olfactory system is not complete. One of the explanatory models, based on docking theory, relies on the shape of molecules and chemistry for interactions. The second model, based on vibrational theory, relies on quantum tunnelling. Use of a combination of both models is not ruled out.

Ehrenfest's theorem relates quantum mechanics (time derivative of position and momentum) and classical mechanics (expectation value of force). As per the decoherence concept, the quantum coherence dissipates as it interacts with the outside world. Actual physical size doesn't matter; what matters is isolation. Quantum nudges (absorption of photons between two states) and quantum stickiness (seen among molecules) are considered useful in explaining many biological processes. Biological structures create a non-interacting and safe space to preserve the quantum state. For instance, cytoskeleton tubules were introduced in Penrose for connecting consciousness with quantum computing (based on quantum effects/properties).

How do genetic switches create different organs? (Example 1)

The cells in different organs vary as a result of 'differential gene expression' [10]. Different set of genes in the genome are activated/repressed by genetic switches that operate through coordinated actions involving chromatic structure (DNA packaging allowing gene expression or silencing), cis-regulatory elements (non-coding DNA sequences acting as promoters, enhancers, and silencers for genes), transcription factors (proteins bound near genes to a DNA sequence for acting as activators or repressors), and epigenetic modifications (heritable changes in genes).

The quantum biologists are exploring how quantum physics may be fundamentally impacting these processes. These quantum physics can also be used to unravel cellular communications, enzyme catalysis, energy transfer, and gene mutation [11]. We cannot shun classical biology and physics and shift to quantum biology and quantum physics. In fact, they are complementing each other.

How enzyme enzyme-based accelerated reactions far exceed classical limits? (Example 2)

It is argued that electrons and protons are able to overcome impenetrable energy barriers through the process of quantum tunnelling in enzymes. It is an underlying mechanism that supports biological catalysis that results in accelerated reactions far exceeding the classical limits [12]. A better understanding and control of quantum tunnelling found in biochemistry shall have transformative effects on bioengineering, drug design, and sustainable chemistry. The quantum tunnelling is also associated with cellular respiration, ATP synthesis, and redox reactions observed in mitochondria. It may be of immense benefit for precision treatments for diseases.

6. Way forward: finding the right mix of approaches?

Nature is much more complex and mysterious than it appears to the human eye. It has motivated and will continue to motivate humans (and similar intelligent creatures) to enrich the existing fundamental stream of knowledge and create new ones in their never-ending quest to unravel the mysteries of nature.

Quantum phenomenon is not sporadic; it is omnipresent–more a matter of observation, perspective, measurement, and interpretation. We need to consider the larger picture and the integrated view, rather than a fragmented one, by understanding the integrative level of organizations, naive realism, generalized quantum theory (GQT), emergentism, morphic field theory [13], and molecular/nano machines. Then we also need integration of quantum physics, quantum chemistry, and quantum biology. From an anti-realism standpoint, expecting to have one unified theory is not a correct approach. It applies even to quantum science.

Integrative levels of organizations

Integrative levels of organizations indicate that constituent units are organized and integrated at multiple levels of complexity. It helps in describing how inanimate objects evolved into animate and social worlds. The complexity (variation) is comparatively higher at higher integrative levels.

Biological components, when integrated, do not always exhibit additive properties. It may result in new rules/properties known as emergent properties. The emergent properties cannot be predicted, irrespective of the availability of knowledge of lower levels [14]. For instance, if a live bacterium is disintegrated, the constituent macromolecules are no longer alive. It is very difficult to predict that these macromolecules, if combined, can result in a living system, including its characteristics (the emergent properties).

Naive realism, GQT, and emergentism

Naive realism considers the 'real world' as it appears to observers. It ignores the cognitive system's role, which acts as a "model builder" and confuses a "world model" with the world itself. The world as it appears is influenced by four human cognitions: oppositeness, temporality, facticity, and freedom-causality linkage. Every perception is cognition of something by someone (oppositeness), while the events in the world are presented sequentially (temporality). The observer lives in a facts-world where "now" generates "prototypical facticity", where freedom and causality are offshoots of temporality [15].

The structure of generalized quantum theory (GQT) draws four notions from quantum physics, namely, system (isolated and investigated), state (system may be in a pure state; mixed states indicate incomplete knowledge of pure states), observable (features at the system level are global variables; known as local variables if linked to a sub-system), and measurement. Thus, GQT relaxes the physics-specific features and widens the applicability of QT beyond physics. It retains quantum notions like entanglement and complementarity. GQT is in sync with the human cognition system and claims that quantum-like features of systems are generic. Two observables are complementary if their measurements cannot be interchanged.

Eliminative reductionism attributes reality to the basic layer, while emergentism, in addition, acknowledges the role of the secondary/emergent layer. The role of the emergent layer is considered subordinate to that of the basic layer. The basic layer description is not adequate to describe the system once it attains a threshold complexity, after which the secondary layers are needed to describe the new emergent features. The downward causation from emergent to basic layer is also possible as part of emergence.

Molecular machines

The biological complexity and astonishing capabilities have also been attributed to molecular machines contained inside the cells that are inherited, in the mitosis and meiosis cell division, in addition to the genes. Each cell behaves as a self-contained unit, taking nutrients, generating energy from nutrients, and carrying out various specialized functions [16]. The molecular machines are structurally complex proteins that facilitate critical functions inside a cell. Key functions, inter alia, include cell division, muscle contraction, transport systems, and DNA replication. Molecular machines are emerging as fundamental for understanding the biological processes within and among cells [17]. A better understanding of their role is useful to reveal insights about living processes and systems, including potential use in medicine. # 7. Proposed postulates The foregoing discussion gives rise to two postulates. First, biological systems employ a mix of quantum properties, molecular machines, and emergent properties to confer advantages in efficiency, speed, or adaptability compared to classical mechanisms. Second, a complete description of biological systems may require quantum mechanics, in addition to classical mechanics and emergent properties.