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Coherence, Compartmentation and Bioenergetics in Living Matter

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Abstract

In reference (Renati, 2020), Quantum Electrodynamical (QED) bases for the emergence of living matter have been reviewed and related to the "irreducible" properties displayed by biological systems (such as morphogenesis, ordered biochemistry, memory, adaptation, teleology, behaviour, and semantics in general). In this short paper a focus is given on the strict relationship between coherence, thermodynamic cycles, matter space organisation at microscopical level, and energy mobilisation in organisms. The interdependence of these aspects is so intrinsic that, we could say, they are two sides of the same coin: the existence of nested hierarchies of coherences and the space compartmentation are the conditions which allow to transfer energy packets on demand and to keep the entropy nest to nil levels.

Keywords: Coherence; Water; Cycles; Compartmentation; Off/In Resonance; Closure; (Ir) Rational Ratios; Fractals

Coherence, Field Gradients and Matter Distribution in Space

The ordering of biochemical activity within time-ordered interlocked cycles and a vast hierarchy of compartmentations in nano and micro sites and niches from molecular scales up to vesicles, cells, tissues, organs, and the entire organism are manifestations of coherence, which is established on the water-matrix, which makes up about 99% of any living system [1]. Indeed, evidence had been gathered that suggest that the dimensions and topologies of living matter's structures might actually result from their distribution and disposition in response to the spatial interference patterns of electromagnetic standing waves in a liquid medium [2-4]. The study of how matter is shaped in space by oscillating fields is known as cymatics, and it occurs in mechanical and acoustic waves [5,6]. In fact, these fields could be electromagnetic or acoustic waves. In the latter case, the well-known dielectrophoretic effect is at play and is related to the various ponderomotive forces developed by time-varying fields on particles in dependence on the frequency, amplitude, and wave-profile of the former, as well as the dielectric constant and the latters' shape [7]. The well-known Clausius-Mossotti relation [8], connect these factors, in particular linking the dielectric constant (underlying polarizability, refractive index, and electrical conductivity) for a material to macroscopic electromechanical quantities, typically density and polarization, and for a linear, homogeneous, and isotropic dielectric, it yields as:

$$\frac{\varepsilon-\varepsilon_0}{\varepsilon-2\varepsilon_0}=\frac{4\pi N_A}{3}\frac{\alpha\rho_m}{M} \qquad \text{(Eq. 1)}$$

being ε the dielectric permittivity of the medium under consideration, ε_0 the vacuum dielectric constant, N_A the Avogadro's number, α the average polarizability of the medium, ρ_m the mass density (Kg/m^3) of the material and M the average mass of the oscillating components in the material. The cymatic and dielectrophoretic dynamics cause the homogeneity of matter distribution in space to break

down. In a standing wave system, nodes and antinodes are formed where the components of the matter are piled up and gathered (nodes) and rarefied (antinodes), respectively.

Speaking in three dimensions (3D), we have patterns of matter, generated by ponderomotive forces exerted by field gradients, arranged in space as membranes, chains and vesicles as the "mould" produced by the interference pattern of such a multitude of standing waves [4]. For a spherical particle of radius r, with dielectric permittivity ε_p, soaked in a homogenous medium with dielectric permittivity ε_m, in presence of a time-averaged electric field gradient ∇E_{rms} ("rms" staying for "root mean squared"), we got an averaged ponderomotive (or dielectrophoretic) force ($< F_{DEP} >$) like:

$$< F_{DEP} >= 2\pi r^2 \,\mathrm{Re}\left\{\frac{\varepsilon^*_p - \varepsilon^*_m}{\varepsilon^*_p + 2\varepsilon^*_m}\right\}\nabla |\overrightarrow{E_{RMS}}|^2 \quad \text{(Eq.2).}$$

Standing waves participating in the various coherence levels are those at work. Coherent oscillations do in fact persist over time and are contained within the boundaries of the coherence domain, spanning over spatial ranges of the order of the wavelength of the electromagnetic mode coupled to the oscillating matter component, and their time scales are of the order of the magnitude of the inverse of their frequency [9-12]. In order to make this point more clearly, please refer to equations 2.2.1, 2.2.2, and 2.2.3 in reference. This entails the construction of compartmentations and matter structures whose topology is determined by the shape of the electromagnetic potential gradients and forces [13]. Particularly, it had been demonstrated that the Anderson-Higgs-Kibble mechanism [14-17] underpins the self-focusing of electric and magnetic fields producing 1D (chains and filaments) structures and 2D ones (membranes and sheets) result from extended coherent boundary surfaces across which the self-trapped fields decay [9,18].

Compartmentation, Cycles and Energy Storage

Many efforts have been made in vain to identify some "centre of control," and more recently to recognize "master genes" which regulate biological rhythms [19], but biologists have long been perplexed about why biological activities are primarily rhythmic or cyclic. However, every organism, even the most basic one, is governed and characterized by a large number of cycles. Their durations (time-scales) range from pico and nanoseconds (for collective electron oscillations) to microseconds and milliseconds for the work cycles of "molecular machines" [20] which carry out bio (electro) chemical work. And the time scales, with wider and wider coherence levels, span many orders of magnitude: from electron motions in redox reactions, to steric changes of enzymes, up to larger endocrine cycles, including tidal, seasonal and circa-annual cycles of a whole organism, or even species populations and ecosystems etc [10,21].

To deepen the vast topic of thermodynamics in living systems the reader is addressed to Onsager [22], Morowitz [23], Ho and Ulanowicz [12,24], Prigogine and Stengers [25], Jørgensen and Svirezhev [26]. Here, a review and causal connection are given among few significant themes that have come up in the literature about cycles and their function in the mobilization of energy. At first, Prigogine hypothesized that "dissipative structures" might be the source of dynamic organization in living systems [27]. Everybody knows the Bénard-Raleigh cells, which appear in a shallow, smooth pan of water (or other more viscous liquids like paraffine) heated perfectly uniformly from below, are the most basic and prototypical dissipative structure [28].

A dynamical phase transition occurs when there is a critical temperature difference between the hot bottom and cold top surfaces. The lighter, warmer fluid rises to the top while the denser, colder fluid sinks, creating an organized pattern of convection cells that, when viewed from the top, resembles a honeycomb. Energy flow and dissipation have been identified by Prigogine as the key players in the phase transition to collective behaviour that creates the "dissipative structure," but in reality, the phenomenon depends on the liquid's capacity to absorb and store the heat energy as well as expand-more specifically, it depends on the creation of a *cycle*.

The system actually must capture and store energy to raise itself from thermodynamic equilibrium, where nothing might happen, in order to benefit from energy flow. Similar to how solar energy flows through Earth, solar energy also travels through other planets. However, only Earth is able really to store (and not simply to absorb) solar energy in forms spendable as work, through its oceans, atmosphere, and chlorophyll, which supports the majority of the biosphere, which, in fact, is a large energy-reservoir kept far from thermodynamic equilibrium. Therefore, energy storage under energy flow, rather than energy flow only or simple energy dissipation, is the key to understanding the thermodynamics of organisms [12,29]. Unless the energy is trapped within the system where it circulates, to conduct work, to build up structures for storing the energy before it is dissipated, energy flow alone is unable to create any significant results. 'Dissipative structures' is still an inappropriate term to describe what living 'energy-storage' structures actually is Ho MW [30]. Indeed, about the cycles-based energetics, we could say that an organism arises when:

- The loops of circulating energy somehow close on themselves to give regenerating, reproducing cycles

(coherence);

- These cycles are many, nested and interwoven one another (super-coherence).

Energy is mobilized throughout cycles, and because of this, it mostly stays stored. Before the energy dissipates to the outside, it undergoes intricate cascades of coupled cyclic processes inside the system. The full spectrum of space-time scales, from slow to fast, from local to global that collectively make up the life cycle are covered by these cascades of cycles. Mae-Wan Ho has presented things in an elegant and intuitive manner [12].

Each living system's cycles and resulting compartmentalized structure are what really allow for high thermodynamic yield, the ability to keep entropy low, and effective energy management. In fact, it is often determined that the organism is an open system whose structure is kept in some sort of "steady state" by a flow of energy and chemicals, and that as soon as that flow is disrupted, disintegration begins and death prevails. But unlike the Bénard cells in heated water inside a pan, that steady state is not a static bulky (thermodynamic) homogeneous phase in a rigid container. Far from it, one discovers ordered heterogeneities or dynamic structures at all scales inside the organism wherein there is no homogeneity, nor static portion kept fixed at any level: rather, there is order in time before there is order in space. Organs, tissues, and cells all have varying degrees of autonomy and closure inside a living body, as do vesicles, pockets, niches, ducts, intramolecular sites, folds, etc [31,32].

Membrane stacks and organelles divide a cell spatially into several compartments, each of which has its own "steady states" of activities that can react immediately to "*external*" stimuli and send signals to other compartments. Because the environment of a small compartment is enclosed within a larger one, which is then enclosed by a more inclusive domain, and so on, the word "external" needs to be enclosed in quotation marks [30,32]. And within the smallest compartment, 'microdomains' with no clear-cut barriers can be separately energized to give local circuits; in addition, complexes of two or more molecules can act as "molecular devices" that can cycle autonomously without immediate reference to its surroundings and carry out a variety of tasks, including the transcription of genes, the assembly of proteins, the "pumping" of ions, the extraction of energy from food, the emission of biophotons, etc., all while operating in small (nano) spaces. The organism is endowed with continuity, organizational closure (a *self*), and the appearance of a dynamic super-coherent *liquid crystal* because the activities in all those compartments, from the microscopic to the macroscopic, are perfectly choreographed [32].

Space Closure and Minimization of Entropy

Dynamic (time) closure, which enables the organism to store as much energy and material as it can and to utilise energy and matter most effectively in cycles, i.e., with the least waste and dissipation, is even more crucial for maintaining a high thermodynamic yield than space closure. In other words, the steady'state' is a collection of space and time-organized processes rather than a single state determined by certain "encompassing" state functions. The organism cannot be described as a "instantaneous-average state" because it has an inherent space-time structure [33,34]. If thermodynamics were to apply to living systems, it would have to do so at each level time by time, ultimately including individual molecules or a coherent domain of them rather than just statistical ensembles of molecules [20,35].

According to Ho [12], it was necessary to "reformulate the Second Law of Thermodynamics" in this regard. To do this, McClare first introduced the crucial idea of a *characteristic time interval (time scale)*, τ, within which a system reaches equilibrium at a temperature θ [20]. The energies contained in the system can be partitioned into *stored energies* versus *thermal energies*:

- Thermal energies are those that exchange with one another, equilibrate throughout the system and reach equilibrium in a time, $t_e < \tau$.
- Stored energies are those that persist in a non-equilibrium distribution, within a time interval $t_s > \tau$, either locally within the system or in such a way that the states with higher energies are more populated than the states with lower energies for the temperature θ.
- The most important type of energy that may be released by any kind of domain is right the coherent energy. Therefore, any form of energy that does not equilibrate or convert to heat within the time interval τ is said to be *stored energy*. A typical time scale of relaxation is actually a space-time scale associated with any particular level of compartmentation, which has its own space-time scale, as was stated above in relation to coherences [20]. As a result, McClare rephrased the second law as follows: A molecular system can only perform useful work when one kind of stored energy is transformed into another. In other words, thermalized energy is seen as being useless for work and cannot be converted into stored energy.

However, also thermalized energy can be used as work [12], it's enough that it is dissipated to a level with larger relaxation time (τ) than the former. In fact, the thermalized energy that is produced during combustion is what the engine of an automobile relies on to do its work. McClare was correct to emphasize that a molecular system can perform useful work through a direct transfer of stored energy without thermalization. Most life on Earth depends

on photosynthesis, which includes the direct, non-thermal absorption of photon energy. For this reason, standard thermodynamic calculations based on the sun's temperature may be meaningless [36]. However, is necessary to take into account just the characteristic space-time scale of the structure or cycles where energy is released and/or stored. Of course, the "mainstream path" in biological processes is non-thermal energy transmission. But in a cooperative system, energy can be focused or channelled to carry out useful work, as in the case of molecular devices embedded in a membrane across which a very high electric potential is settled (which, in fact, can function as a " Maxwell's demon") [20].

The most crucial point is that in a system with space-time organization, 'thermal' (rich in microstates) energy in (and for) a small compartment is nonetheless stored energy within a larger compartment enclosing the former. This is true because the sub-levels' time scales are longer than the successively greater levels of compartmentation. And when coherent oscillations take place, this becomes evidently clear. Each level of coherence has its own space scale (determined by the wavelength, λ, of the relevant electromagnetic mode) and time scale (determined by the resonance frequency, ω_r), both of which are independent of one another. Therefore, the characteristic time, τ, first proposed by McClare could be calculated as $\tau \approx 1/\omega_r$ Let's think, for instance, of the different space-time scales of two kinds of coherence in water: on one hand electron oscillations between sp^3 and 5d levels (wavelength of the order $\lambda \approx 100$ nm and resonant frequency $\omega_r \approx 5 \cdot 10^{13}$ Hz, and energy gap $\Delta_g \approx 0.17$ eV (at 300K) De Ninno, Del Giudice, Gamberale, & Castellano [37] and on the other hand molecular dipole rotation (wavelength up to $\lambda \approx 500$ μm, resonance frequency ωr ≈ 5·1011 Hz and energy gap Δg ≈ 0.02 eV in the bulk, possibly increased when interfacial conditions are considered [38]. If sufficiently "mild" (so as not to throw out of coherence the components in the second level of hierarchy), the microstates released from the first level represent still ordered (stored) energy for the second (bigger, slower) level.

Mae wan Ho [30] very keenly proposed that a more adequate restatement of the second law of thermodynamics might be as follows: *Useful work can be done by molecules by a direct transfer of stored energy, and thermalized energy cannot be converted into stored energy* within the same system*, the system being defined as the (spatial) extent to which thermalized energies equilibrate in a characteristic time.*

Mae-wan Ho's improved version provides a mechanism to define a "system" in terms of the degree of thermal equilibration in a characteristic space-time. Because the piston is exerting force externally to the system that contains the thermalized energies of the expanding gases, the thermal engine relies on thermalized energy produced by the combustion of fuel.

Two very different ways of carrying out useful work most efficiently-not only slowly (i.e., at equilibrium) according to conventional thermodynamics, but also quickly-appear from the explicit introduction of time scale and, consequently, of space-time structure. Both of these methods are reversible and carry out to their fullest potential efficiency because, ideally, no net entropy is produced within that space-time compartment [23,29]. Naturally, terms like "slow" or "fast" refer to a space-time domain's (and cycle's) relative motion relative to that timescale.

An example of a "fast" process is the release of a photon from a site and its subsequent adsorption by a different structure with comparable relaxation times. Another example is the transfer of a charge to a molecule, which results in a subsequent shape change that occurs at a rate that implies the duration of the two shape configurations is of the same order of magnitude as the last of the excited electric charge.

A "slow" process is one that proceeds at a rate that is equal to (or slower than) the duration of time needed for all exchanging energies to balance out or disperse throughout the larger system. Think about the mechanical energy, or work, produced by the translation of the piston in an engine while the microstates of expanding gases are entropically thermalizing. At this level, the entropy is increasing at the molecular level of the gas, but at the next, larger level of the piston, it is converted into work because the latter's characteristic space-time scales are much slower and larger than the one of the gas microstates. The combustion chamber is contained within the entire engine, making this possible. Compartmentation and closure are thus crucial to allow such energy exploitation from a level to another.

Since the energy that would thermalize at a given small scale is still usable as ordered energy at a larger level, the nested compartmented structures' manifold of characteristic space-time scales permits energy exchanges among the various levels both slowly and quickly.

Because of the high degree of topological organization, the organism has enormous amounts of stored energy. Energy is stored in a variety of structures, including complex chemical molecules, macromolecular conformational fluctuations, concentration gradients across membranes, electric fields produced by charge separation, viscoelastic fields caused by mechanical strains, which may be local to a single protein or may be global to the entire cell or tissue, and, of course, ubiquitous coherent states [39].

It is far preferable to start with the novel idea of "stored energy" developed by Ho [12] than with the conventional "free energy." Free energy cannot be well-defined, nor can it be assigned to any single molecule. Without knowing how far from equilibrium the reaction is, even changes in free energy cannot be characterized. McClare originally used a characteristic time interval to characterize "stored energy," but that definition has now been expanded to include a characteristic space-time [12,23]. Stored energy is a precise term that is defined on the space-time domain of the processes involved. It is explicitly dependent on space-time differentiation. The concept of stored energy applies to both individual molecules and the entire organism. The organism can be thought of as primarily a super-domain for energy storage, and the energy that is stored there is coherent energy that can perform work in the particular space-time domain in which it is kept.

Fractals and Irrational Ratios in Energy Mobilisation

The final major problem to be solved is how energy can be mobilized only when and where it is needed, alongside resonances of coherence is always in force. Fractals are ubiquitous in Nature [40] both in inanimate realm (coastal lines, snowflakes, hurricanes, lightnings, dry soil cracks, eddies in rivers, ratios among planet orbit periods, etc.) and in living systems (trees, shells, flowers, pine cones, blood vessels, healthy heartbeat patterns, bone trabecular structure, neuronal networks and healthy brain oscillation patterns, allometric scaling of organisms and cytoplasm-about compartmentation and nested-ness – as well as cytoskeleton-about branching and networks [41]. Fractals' approach and study provided the necessary theoretical tools to comprehend enzyme kinetics, mass transport, and thermodynamic flow-force interactions (like the Onsager's ones [22] in the cellular microenvironments. Fractality in nature is not merely intended to be geometrically, but also dynamically [42].

The relationships between what have been discussed so far and fractals is promptly clarified by a series of recent works [43-45], wherein Vitiello, et al. have excellently shown that a functional representation of self-similarity is mathematically isomorphic to squeezed quantum coherent states, where Heisenberg's uncertainty is minimized. It appears that quantum coherence u fractals to underlie their ubiquitous recurrence in nature [46]. In other words, self-similarity and deformed coherent states can both be used to express one another. This enables us to claim that self-similarity is the macroscopic manifestation of the dynamics of the deformed coherent states, or even that fractals, or self-similar systems, are macroscopic quantum systems in the specified sense, i.e.: they exhibit macroscopic dynamic features (growth or formation, morphogenesis, bioenergetics, organization, etc.) that cannot be explained without reference to underlying (microscopic) quantum dynamics.

In micrographs of the cytoskeleton [47], the fractal dimension has been analysed and they discovered that the cytoskeleton acts as a *percolation cluster* (or a *random fractal*). A fluid injected into a centre of a percolation cluster, which is a collection of holes or sites connected by a lattice, percolates throughout if a threshold of connection is overcome. The existence of a *percolation threshold* below which the spreading process is constrained to a finite region is the hallmark for a percolative dynamics. The percolation probability, *P(p)*, is the likelihood that an injected fluid at a side will enter and be absorbed by an unlimited number of locations. The cluster behaves as a locally connected system below the percolation threshold, and as an infinitely connected system above it. As the number of holes *p* rises, the percolation process shifts from local to global connectedness close to the critical probability P_c.

In ref. Tang L, et al. [48] they used an optical microscope with video recording to track the movement of fluorescent particles in living cells and discovered three modes of movement: local mode, where the particle is confined in a small area of cytoplasm (radius 0.64 m); extended mode, where the particle has an extended trajectory (radius 2.73 m); and a mixed mode, where some of the trajectory is local while other parts are extended (average radius 2.28 μm). Plotting 25 graphs in a log-log scale of the linear segment size (into which were subdivided the total track) versus the number of segments, showed straight lines with slopes (i.e.: fractal Hausdorff dimension) varying from 2.04 to 1.35, and independent of the size of the particles tracked.

The main "percolating fluid" in living matter, of course, is energy, travelling along molecular backbones and membranes in form of solitons, photons, polarons, phonons, spin waves, etc [18,21,49-51]. All of these are forms of ordered energy coming from the underlying nested coherent dynamics. The aforementioned studies [47,48] demonstrate that, when cytoplasmic activities rise over a certain threshold, they exhibit a global resonance behaviour in which energy is permitted "to percolate" wherever a path is left available. To ensure that energy does not "leak" out of control, this process can be adjusted or turned on and off. Shall we examine how water cycles and coherence are essential to understanding this sophisticated "mechanism". Coherence in water (for its special electron excitations spectrum, including a dense band of collective states between 12.07 and 12.60 eV) is able to be finely tuned in dependence of excitation released or collected by CDs. This is how resonance can be tuned, yielding a mechanism which allows coupling and energy transfer from a level/compartment to another, and is the

key aspect to understand why fractality lays at the basis of mobilisation of energy [12].

Firstly, we need to consider the ratios between the proper frequencies and energy sizes within the relevant scale window in the system which shows patterns and dynamics, such as cycles and stationary oscillation frequencies. It is interesting to determine whether these ratios are rational (or even integer) or irrational when considering the frequency, the oscillation period, or the wavelength of coherent oscillations cycles. Two possibilities would result in either *closure* and local autonomy or *resonance* and phase coupling. Secondly it is interesting to know whether these two conditions (to open or close the energy transfer by resonance) are arbitrarily switchable ("tunable") from/to one another, as to estimate whether these different work regimes/layouts are easily undertaken by the (sub) system [12].

In their article [52] on the distributions of rational and irrational numbers, Panchelyuga and Panchelyugaoutlined an intriguing aspect, demonstrating that the latter are arbitrarily close to the formers and that the rational numbers distribute unevenly along the $\mathbb{Q}$ set and specifically in a fractal way (self-similarly, increasing the width of the considered intervals among the density-maxima of the two distributions, rational and irrational, by moving towards higher values in the number set).

What is interesting is right the "numerical proximity" existing between rational and irrational numbers at low numerical values (as in the [0,1) subset of $\mathbb{Q}$), that express the ease to pass from a condition of resonance (rational, or even integer, ratios among values of dynamical quantities of the system) to a condition of closure, uncoupling between oscillators (irrational ratios among the values).

A condition of resonance, for instance, occurs between a system named q and another system named p if the ratio, r, of their frequencies ωq and ωp, is a rational number: $\omega p / \omega q = r \in \mathbb{Q}$. If $r \in \mathbb{N}$ we speak even of harmonics. If $r \in \mathbb{Q}^*$, no resonance exists and the systems have non-commensurable frequencies, and the phase space is described by KAM toroids (by Kolmogorov, Arnold and Moser), or quasiperiodic orbits [53,54].

Rational numbers at low values of the $\mathbb{Q}$ axis especially, have dense neighbourhoods very close to those of the irrational ones, as demonstrated by Panchelyuga and Panchelyuga. This indicates that transitioning from dynamical closure to percolation (energy transfer by resonant coupling) requires very little tuning-shifts in systems where multimodal coherence is in force (like that's the case for the water-based matrix of any biological matter). Irrational and rational number distributions are the "tuning ground" across which the same physical system can modulate its internal constraints in order to switch its quantities (as work frequency proper of some nested structures) from the conditions of *closure* and local autonomy to the conditions of *resonance* where coupling and energy transfers (along with electrical charge and matter transfers) can be performed "on demand", in suitable moments and places.

Of course, changes in living systems can occur very quickly at smaller space-time scales when dealing with processes like electron or ion oscillations, vibronic states of molecules, protein folding and unfolding, cyclic stresses in enzymes, and so on [12]. The ability to tune from non-resonant (irrational ratios among frequencies) to resonant (rational/integer ratios) and vice versa may now be explained physically. It is important to keep in mind that this possibility is directly related to the unique characteristics of the water molecule's spectrum, which offers us yet another justification for considering this "alchemical" component to be the *molecule of life*.

As outlined in ref. Renati [13], water has the special condition by which in between the 5d orbital and the ionization threshold (0.53 eV above) a manifold of densely packed collective electronic states exists. These states, the ones associated to the so-called cold vortexes, have energy-spacings of the order of 10-10eV and can be selected through several ways which, as a matter of fact, require no energy expense [55,56]. Indeed, the oscillation frequency could be easily changed by phase variations in time due to tiny electric currents among CDs (acting like Josephson junctions [1,57], Smith as well as by simple mechanical strains within the cytosol, for instance, or through tiny variations of electric potentials across membranes (acted through piezoelectric effects or by releasing some ions) and many other mechanisms. Also tiny magnetic field variations associated to looped cyclotronic currents [1] can induce shifts in the proper frequencies, switching compartments / domains from irrational (closure) to resonant (open) mode and vice versa.

We believe that numerous studies should be conducted in order to confirm these theoretical predictions, but it is conceivable that such readily available "continuous bands" of possible states could be found in many more degrees of freedom on which coherent domains establish in addition to the sp^3-5d oscillation, such as on ions coherent domains and not just on water molecules. Yinnon, et al. [58] other possibility could be: coherent oscillations of ortho-para nuclear spin configurations in biological water [59], phonons bands, polaronic sates, spin density waves, etc.

The new and vast landscape that is being revealed enables us to view living matter as a collection of "interwoven quantum-based devices" in which various physical quantities (such as electrical and magnetic fields, mechanical-sound waves, density, pressure, frequency, temperature, electrical charges, masses, dipoles, spins, photons, phonons, etc.) interact with one another and express a truly symphonic behaviour in which everything is dependent on everything else, despite maintaining at an emergent level its own "dynamical identity" (the emergent self), closure and local autonomy. This kind of dialectics is just what any living system in essence is.

In order to reward us of fruitful results, such investigations should be run on the basis of the theoretical approach reviewed so far, out of a perturbative description of the interaction between matter and electromagnetic fields [60], which is possible only by adopting the powerful and consistent tools of quantum field theory, gauge field and symmetry breakings theories [11,61].

Golden Means in Nature

Finally, it is now possible to consistently derive some considerations about why nature is so fond of fractals. It is evident that living systems' well-known astounding capacity for managing their own internal energy is a result of their cycle-based operation [62,63]. As it's known, trying to replicate the same chemical pathways performed within a single cell performs every second, beyond needing a lab as large as a nation, would imply a dramatic fail: i) no cycle could be maintained and the reactions would not return to the starting point (no autopoiesis), and ii) the efficiency and the speed of such reactions performed in a laboratory would be hugely lower than in vivo [64,65]. This would be the case because, out of living matter, in absence of nested coherent hierarchies interwoven and tuneable, no time-ordered meeting of the chemical reagents would be ever possible. Super-coherence is the physical requisite for the existence of cycles, coherent, ordered, rhythmed, coupled, oscillations at several, nested, space-time structures [12].

The living phase of matter, i.e. a water-based coherent matrix inhabited by a minority of other molecular species, origins its typical compartmented feature responsible for the minimization of internal entropy, of the energy needed and dissipated, from nested super-coherence. Coherent domains of several scales, pertains to several cycles interlocked among one another, to each of which typical time and space scales are associated (from oscillation periods of 10-13 sec for electrons and ranges of the correlation of nanometres, to heartbeats, neuronal burst in brain spanning tens of centimetres, up to hormone cycles as long as a month, or seasonal rhythms and the whole lifecycle starting with conception and ending with death).

It is impossible to change the settings at one level without impacting all the others since the levels are locked together like in matryoshkas. These levels are not frequency multiples of one another by default, but they are all phase-coupled (like a band playing at the same pace). If they were, there would be no way to compartmentalize or store energy because resonance would transmit energy everywhere. In situations where nested-ness is combined with irrational ratios and non-resonance, fractal structures result. This ensures security and independence. However, in order to mobilize energy, this condition must be easily modulated. Fractality enables right to enter resonance conditions through minute adjustments to work-frequencies, allowing system components to couple and exchange energy matter and electric charges. As also Mae-Wan Ho and al. hypothesized [66], now it's very clear why fractal structures are used so extensively in the living world: they have both a functional origin (being the fractal, irrational ratios among self-similar structures at the various space-time levels, those ones that guarantee a stable autonomy despite the system's openness) and a dynamical origin (resulting from the nested-ness of coherences and cycles).

Thus, Nature (physis) is able to "kill two birds with one stone": living fractals are associated with irrational numbers such as the golden mean and in order not to enter resonance [52,66]. The activities can still be distinguished because of this. However, since the fractals are also in close proximity to harmonics that do resonate, switching from fractals to harmonics makes it simple to achieve phase coupling and energy transfer through resonance. According to Haramein and Rauscher [67], the golden ratio is involved in the whole scale range in nature, this reveals an underlying fractal (holographic) organization of physics that extends beyond the biological domain. It's possible that this transition from fractals' (irrational) ratios to rational ones, or even integer harmonics, occurs at the same time as the percolation threshold where local small-scale systems connect to global levels.

Conclusion

In this short review, a focus on how the essential micro-compartmentation of living matter is the key feature by which both a minimization of entropy and the not-straight-forward applicability of the second law of thermodynamics (as tout-court it has been conceived for homogeneous, bulky material systems) hold. The compartmentation is the direct consequence of the existence of stationary oscillations associated to the self-trapped electromagnetic (and even acoustic) waves coherently coupled with the water-based medium constituting living matter on one side, and of field

gradients across coherent domain boundaries on the other. In turn, the existence of compartmentation is what allows living organisms for the possibility to use possible thermal energy (produced at a given compartmentation level, having short relaxation time) as work, or free energy, at a larger level (with longer relaxation times, and lower proper frequencies). This guarantees entropy levels close to zero within the organism, dissipating disorder out to external environment.

Eventually the precious typicality of coherent water, able to give place to a huge manifold of coherent states (associated to the quasi-free electrons collective states), having energy (and proper frequency) spacings smaller than one billionths of eV, is the key to switch from conditions of closure and un-coupling among different systems, to the resonance conditions, where energy can percolate out of a compartment to reach another site only when needed. This is a proposed mechanism by which living matter works by transferring energy only in the right places and at the right moments, despite a common coherence, with a whole multiplexed phase Eigen function, is always in force (which guarantees the emergence of an identity, an emergent self). Fractal properties are the direct transduction of underlying squeezed coherent states in a nested hierarchy and are also related to the distribution of rational and irrational numbers along the real number set. This explains why biological matter "loves" fractality and irrational ratios (like the golden mean). To acknowledge such a picture of living matter would improve the consistency of the research approaches in describing biological systems and would let a quality leap also in the growing branch of the so called "quantum biology".

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Conflict of Interests

The author declares no conflicts of interest.

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