Electrodynamic coherence as a bio-chemical and physical basis for emergence of perception, semantics, and adaptation in living systems

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Abstract

Despite the successes earned in cataloguing and finding the role of the most of molecular components in living matter, the "biochemical and molecular" perspective, popular in biology, medicine and genetics, is unable to give account for crucial topics as the faculty of living systems to "feel", to "perceive" what a given stimulus implies (means, indeed) for their survival. Condensed matter physics too, if bounded to a local, short-range, and perturbative approach, fails dramatically. This is also due to the role commonly assigned to water – actually the main constituent of living matter – deemed for long time to be merely chemical (as "solvent" or a reactant/product). Nonetheless, today many evidences show how living matter can be right conceived as a super-structured coherent water-based matrix, suggesting that the characterization of bio(electro)chemical and physical processes undertaken at molecular level in living matter, would let us unable to answer a question like this: what allows an amoeba, moreover without any neurons, to "know" to get closer to a nutrient or escape away from a toxin? I propose that to pursue such a fundamental inquiry it's necessary an essentially *relational* approach, that is: to consider the living being at its grounding as the outcome of a physical history of *relationships* where symmetry-breakings, dissipation and coherence yield the emergence of the living state of matter, conceivable only as a time-dependent *open process*, and not as a portraited "body". The effective tools to build up such an approach may be retrieved in far-from-equilibrium thermodynamics (TD), symmetry-breakings and gauge-fields theory, science of complexity, within the framework of a Quantum Field Theory.

Indeed, within a field-view of matter, and of water especially, as it has been developed by a Quantum Electrodynamic (QED) description of condensed matter, it's possible to give account for a physical basis too such an epistemologically elusive, though crucial, feature of living systems (i.e.: perception and meaning). The emerging landscape allows some important meditations about adaptation, evolution, ecodynamics, and about different conceptions of complexity and "information" in living realm. Furthermore, some neuroscientific themes like consciousness, qualia and their links to artificial intelligence could be supplied with due insights.

Keywords: *water, nested coherences, phase-locking, dynamic order, cycles, fractals, perception, meaning.*

Used abbreviations: Classical Physics: CP; Coherence Domain: CD; Information Technology: IT; Nambu-Goldstone: NG; Mechanical Statistics: MS; Quantum Field Theory: QFT; Quantum Mechanics: QM; Telecommunications: TC; Thermodynamics: TD.

1. Introduction: presentation of the problems

The most striking property and feature of living beings is their ability to *respond* to meanings and not only to react to (possibly measurable) stimuli carrying energy and/or matter, like any inanimate object does. To "respond" is something related to the faculty of a system to "feel", to "perceive" what a given stimulus implies (means, indeed) for it. Thus, in order not to invoke any infused "soul" or "entelechy" animating the living "body" as a puppet (and thus opening an irreducible and unjustifiable ontological fracture), in an honest physical and truly holistic attitude, some crucial questions to ask could be: which is the difference, physically speaking, between *responding* and *reacting*? When do matter systems (as living ones) become able to respond and not only to react? Which are the necessary and sufficient conditions so that matter can be in its "living phase"? To introduce some issues annexed to perception, I'll bring also some apparently trivial examples which, however, give us the chance to notice how this kind of reflections, commonly disregarded, are crucial also to set up fruitfully any kind of inquiry about living systems.

1.1 Limits of searching for semantics at molecular level

In a purely mechanistic approach, many people take for granted that the *reasons* for *emergent properties* (like physiology, movement, behaviour) can be fully found by investigating the micro-components that constitute the same living systems, like molecular biology and genetics (more or less explicitly) have been suggesting for decades (Lieberman & Ricer, 2014).

By starting from the study of single cells, possibly even observed *in vitro*, proceeding through smaller and smaller scales – from intracellular apparats, down to molecular species and their reactions, electric potentials, shape-matches among substrates and enzymes, etc. – the foundations and reasons for some emergent features (such as, physiology and behaviour, as well as adaptation and evolution) are thought to reside mainly in what the system "is made of". And in the view according to which chemical species meet each other through diffusion, generally the living matter is still thought of as a system where random dynamics and chance may rule the play (Monod, 1971).

This approach – imported *tout court* from some 'hard sciences' – belongs to *methodological* or *epistemological reductionism*, already applied with more than discrete successes to the study of inanimate matter. Its stance could be resumable as: once defined the measurable macroscopic variables in the environment (as temperature, chemical composition, fields), the underlying reasons for the resulting processes expressed by a living system (such as respiration, movement, mitosis, secretion of pheromones, just to make random examples) are all traceable back to the dynamics of the "elementary" components at the molecular/atomic level. Nonetheless, beyond the fact this direct causal relationships doesn't hold in general for complex (even non-living) systems (Baranger, 2000), there is a formal fail and an ingenuity, here: it is acceptable for sure that a physiological state can be well described by the array of underlaying biochemical and physical processes that correspond to it because, in fact, the former **is** right that set of molecular dynamics and physical states of the components. Quite different, however, and far from being flawless, is claiming that the latter are the *cause* of the former. In fact, the two things – physiology, for instance, and the underlying "choir" of biochemical processes – do coincide and are only distinguished by the descriptive level at which they are concerned.

Therefore, a bunch of questions pops out:

- If the two things – physiology and the underlying biochemistry – are the same dynamics just observed at different scales, which are their real causes and dynamical laws (ruling their development)?
- Is it really consistent to think that at microscopic level diffusive (random) dynamics rule the molecular encounters when they should anyway underly (dramatically non-random) emergences as adaptation, sensing, behaviour?
- How is it possible that such large amounts of molecular micro-components, constituting even a single cell, can origin such specific and "suitable-to-live" collective ensemble (regardless whether observed under the biochemical, physiological, anatomical, or behavioural point of view)?

It will be discussed that these three questions can be answered through the well-established feature of *coherence* in living matter (Fröhlich, 1968), (Li, 1992b), (Popp, Warnke , König , & Peschka, 1989) (Voeikov & Del Giudice, 2009) (Ho M.-W. , 2008), (Del Giudice, et al., 2005). However, till now, attention has been payed mainly to the second and the third point. The first one pertains to a tangle of physical, as well as epistemological, issues which I'd like to frame and unravel a little.

Undoubtfully, it is extremely useful to determine the basic biochemical mechanisms from which we identify the precise synthesis-cycles in cellular activity, associated with the respective physiological expressions. This also allows us to intervene effectively in disease processes, changing their (even harmful) symptomatic trajectories. However, one thing is to describe in detail the underlying biochemistry, electrophysiology, genetic expression, etc. of an emergent living process; another thing is understanding **why** it comes out and which is the fundamental dynamics (i.e.: for which reason and/or purpose it occurs, in regard of the living system perspective).

So, if during the just passed decades, the main question marks concerning the physics of living matter were about (i) how a stable far-from-equilibrium state is maintained, (ii) how bio-communication is so efficient, (iii) how the molecular encounters in biochemical pathways occurs so quickly and precisely (with such little energy expenses), and (iv) which fields (and how) could be at work in morphogenesis; today, we think there is an even more urgent, fundamental, issue to be tackled. A question, to us, that biology has concerned not enough. The question is: *how can organisms be able to* respond *in dependence on what a certain stimulus or environment* means *for them, for their homeostasis, their well-being, stability, functioning, survival…?* Therefore, the theoretical issue is*:* how *can living matter assume states which are consequence of semantic relationships?*

By speaking of "meaning", in regard of a living system, we denote "something" pertaining to how, *qualitatively*, the relationship/interaction with the environment, and the consequent internal state engendered within the living system by such an interaction, are actually felt, perceived. By speaking of "semantics" we refer to this general ability to be sensitive to, and engender, *meanings*. This said, the questions above could also be resumed as: *what does it mean "to perceive", physically speaking?*

A measuring apparatus detects, records, reveals something; a living system *perceives*, feels, makes *experience*. The act of perception is not passive and it's not just a reaction, to perceive means to modify the state of the perceiver in consequence of the interaction with the perceived. Del Giudice in one of his conferences, in 2012, said that there's a big difference in kicking a stone or a cat: the second beyond, to produce reactions according to Newton's laws (acting a mere reaction), will express a *response* that it's not uniquely, nor directly, describable through such laws (despite they, together with those of TD and QED must be at work anyway!).

We would like to consider a couple of (though trivial) examples to show how the dependence of the living state on the *meaning* of what is experienced is ubiquitous. Indeed, it is a daily fact to observe how physiology is in strict dependence on which the conditions a living being is experiencing are. We may think of wild animals as well as of human beings:

- an antelope smelling a lion hidden somewhere behind bushes runs into a deep change in its own breath and heartbeat rate, adrenal secretion, ocular mydriasis, neuro-muscular hyper-tone, olfactive and auditive sensitivity amplification, and so on;
- a mother reading a novel, relaxed on the sofa, if answers a phone-call referring her son has just been injured in a car accident, changes dramatically her physiology status (possibly cold hands and feet, variations of skin conductance, increased heartbeat rate, adrenaline and cortisol incretions, and other outputs, also similar to those in the previous example).

Obviously, to any "macroscopic" expression, a consequent different chemical portrait is associated (hyper/hypo secretion of these or those neuropeptides, hormones, enzymes, etc. changing in basal muscular tone, activation of specific districts of brain and regimes of neuro-ception, and so on). When the "stress" or *danger* is over (because the lion has been spotted and gone away, for the antelope; or the son, during healing, gets out of risk, for the woman), another change of their physiological parameters will occur, pointing (not straightforwardly) towards a normalization. In mammals and other complex animals (as reptiles and birds) all these stress/relief processes pertain to the activation of the autonomous nervous system (ANS) (Porges, 2012) and the stress-related physiological activations are said to be in "simpaticotonia", while the recovery and post-stress processes are unfolded during the "vagotonic" (healing, recovering) phase (Selye, 1936), (Cannon, Bodily Changes in Pain, Hunger, Fear and Rage, 1929), (Cannon, 1932), (Mason, 1971).

It's quite evident that what in fact activated one kind of physiology (and biochemistry and biophysics) or another, is due to "what the experienced situation does really *mean*" for that specific living being in that moment (the antelope or the woman).

Why are we talking about this? Because, as we hinted above, contemporary hard sciences do not describe at a fundamental level the connection between meanings of the stimuli and the consequent biochemical and biophysical (material-energetic) outcomes, such as physiology, which the formers imply, despite relationships between, for instance, *stress* and *diseases* (we could say "special regimes" in physiology) are well-known in mammals like humans (Maté, 2003), (Everly & Lating, 2019). This "special kind" of stimuli in fact is given by the *semantical* quality of what the living beings are experiencing: the physiologic activations in the antelope or in the woman above are not due to the "energy" (nor to the phase) of a signal, nor to the "chemical reaction" of certain molecules that arrived from outside at the sensing systems (despite a chemical transduction is present).

Indeed, it's not consistent to assume that the antelope showed up a given physiology (related to the alert state) *because of* the chemical reactions between some molecules coming from the lions and some others belonging to the antelope's organism, despite this is an event which in smelling occurs for sure. But this is the *way* (how) the interaction occurs and is processed, not the *reason* (why) for the antelope's physiological and behavioural response. Indeed, if the smell of the lion would mean for the antelope something different from "a threat for survival", in the same antelope, the same lion's molecules, would activate different physiologies.

We can notice this fact again in our everyday life, for instance with cats and dogs: there are some cats that fear dogs, others that, conversely, sleep and groom with them (Dog and Cat grooming each other), (Cats and Dogs sleeping together), and even some that may change their behaviour during their life. The dynamics does not work like this: «some (smelled) molecules of dogs + some (receptors) molecules of cats react together and produce, according to biochemistry, pre-fixed outcomes in physiology and behaviour of cats». That's not the case, despite biochemistry constraints hold at all and ever, of course! Actually, everybody knows (heuristically): the consequences of the interaction, the chemical pathways underneath given physiologies and behaviours (related to a danger /safety response, for instance), depend on what the cat has been experiencing. They depend on what the experience of given situations, object, animals, molecules, sounds, etc., really do (or did) mean for the cat's survival and homeostasis. For living beings, mere "events" do not exist, but just "what the events mean" for them; what matters it's not the stimulus per se, but what it implies. This is an objectively subjective fact:

non-invariant, context and history-dependent causal relationships (Logan, 2012), (Renati, 2015) and this holds for a cat, for a fungus, a paramecium, a tree, as well as for a human being.

So, the interesting point is that the very basic level of biochemistry constituting the living matter of an organism (ruled by physics of course), despite obeys strict rules (the laws of physics and chemistry) and should thus produce fixed outputs when the same molecules react in the same conditions (thinking the chemical compositions of the smelling cat as a default), as matter of fact, cannot be considered the level through which to predict what will happen *tout court*.

Thus, within a system able to *perceive*, able to *respond*, the chemical pathways seem to constitute "how" and not "why" a given response (a physiology, a behaviour, a "choice") is expressed. The "reasons" appear to lay in which is the *meaning* of what is being lived: a category which joins together *causality* and *finality* in the essence of what a living being is (i.e.: thermodynamically an *open process* – not a defined object – resulting from *history* and *memory*, oriented to *purposes* and *goals*). After showing the theoretical background in section 2 about open-ness and coherence, it will be clearer why this is the case.

1.2 Perception is not detection, response is not reaction

To perceive, to know, the environment means to undertake a change of the internal state in such a circumstance. But, of course it's not enough, because a beef steak being cooked is changing its internal state, but it's not "perceiving", nor "knowing", the environment at all. As I discuss in sections 2.2 and 3.1, the real difference is made by the special kind of physical states which are implied in "alive" systems. That kind of states which allow us to speak of "knowing something" advisedly. However, we can already guess that the change of the state of the system as a *whole* is a necessary condition occurring in any interaction.

It's important to keep in mind that the *perceiver* is always also the *perceived* because its own modification (the change of its physical state) is right the dynamics which "informs" the living system itself about what the context, the stimulus, the environment in general implies for its survival; otherwise we would be speaking only of virtuality. When we speak of "state" we mean in a physical sense: in a quantum view, for instance, we could be speaking of a comprehensive time-dependent wave function representing the eigenstates of the quanta constituting the system at a given time.

The occurrence of a given "state" of the living system implies annexed outcomes pertaining to how matter and energy (and several annexed observables) configure. To make few examples, think of: the performed biochemical paths, electric potentials, pulsation frequencies in microtubules in the cytoskeleton and in proteins on the membrane, and many other processes at the molecular scale, up to, at a more phenomenological level, physiology, movement, reproduction, behaviours... . Thus, dependence of the assumed states on meanings refers to another striking aspect of living systems: their apparent capability to make "choices", to "behave" and, at the basis, the ability of *sensing* most of what really matters for their survival (inside and outside themselves).

How an amoeba (without brain nor neurons) is able to "decide" to move towards nutrients and to move away from toxins? This is a simple and a deep question, because it is not answerable through chemotactic avalanches triggered by key-lock receptors' modifications (in consequence of meeting a molecular species in the external context) which activate cascades of effector proteins making the cytoskeleton to produce the adequate movement of filopodia. This is not enough to understand *why* the amoeba is able to behave as told, because, from this chemistry-based point of view, it is not understandable how in one case the cytoskeleton movement brings the amoeba closer (to the nutrient) while, in the other case, it brings the same amoeba farther (from the toxin). Said otherwise: the chemicals involved in reactions underlying the movement of cytoskeleton should show activities somehow dependent on the spatial configuration of the amoeba with respect to the environment and the provenience of the stimuli. Actually, but from a physics perspective, that's the case, but it cannot be accounted for without dealing with the special (holistic) physical state of living matter.

As we can see, the process of *perception* (and not only of sensing), constitutes the nodal keystone intersecting two apparently irreducible extremes: a postulated *free will* on one hand and a pre-determined mechanistic "functioning" ("à la Laplace") on the other. Indeed, both the single stances, considered *per se*, are incorrect and inconsistent (Renati, 2016).

As a matter of fact, living dynamics is the decisive process where a deterministic *emergent* "freedom" is shown: "*deterministic*" because – unless referring to some arbitrary metaphysical hypostatized causes – all the levels at the foundations must be tied by, and obey, physical laws and constraints; however their complexity produces an emergent unpredictability and a so deep sensitivity to initial conditions that it results (and it's perceived) as (a sort of) *freedom* (as to yield an identified *self*). This is why to speculate on the level which handle freedom and causal determination separately, is totally unsatisfying and inadequate, as the same as to consider chance and necessity as two ontologically distinguishable categories.

In dependence on what is experienced (which implies necessarily much "more" than simply to interact or to detect) the living matter configures itself in physical (and chemical accordingly) states which are at the same time both the *consequence* of the experience and the *premise* for keeping the living system itself as alive as possible: the "special" physiology expressed by the antelope while it "feels" threat or danger, increases its chances to survive; like the emergent movement of the amoeba (to get closer to the nutrients or farther from the toxins) increases its chances of survival.

Of course, looking at evolutionary process, we can say that these physical states must give origin a *history* where each state produced by the system is dependent on all those ones came first of it: this is what allows *adaptation* and *evolution*, since a *history* can be kept and "stored" step after step (right like happens in phylogenesis).

The possibility of keeping a history and of expressing the living states dependent on it and oriented toward (adaptive) purposes, is right what make the difference between *action-reaction* links and *stimulus-response* ones; it is what makes the difference between *detecting* and *perceiving*, between *measuring* and *experiencing*, between the *living* and *non-living* phase of matter where there is actually no distinction between "hardware" and "software" (Logan, 2012) (Renati, 2015).

Indeed, what we know as "instinct" in animal and plant species is right that array of previously developed behaviours and responses which guarantee chances of survival. Well, such an "informational baggage" is right the *semantic packet* which has been possible to build up thanks to the special physical state of coherence typifying living matter. We may intend that the reactions performed at chemical and physical levels are somehow "the tool" by which the meaning, that some given stimuli, situations, scenarios have for the organism, actualizes itself. The reasons of whichever living expression reside in "what the context (outside + inside) implies, that is: how it transduces into a (shared, holonomic) physical eigenstate".

This kind of "memorization", however has nothing to do with a digital-like sense (as nowadays it is often assumed (Yang, 2014) (Sheth & Wang, 2018), (Church, Gao, & Kosuri, 2012)), because it pertains to the relationships undertaken among all the unreducible states occurred in the dissipative history and it's not a stripe of bits or q-bits, it's fully analogical, relational, (Renati, 2015) (2016) and pertains to the configurations "living system + environment" (Vitiello G. , 2001).

In the light of a field-view of matter (Preparata G. , 1995) where, coherence plays a key role in building up its living phases (Del Giudice, Doglia, Milani, & Vitiello, 1985) (Del Giudice, et al., 2005), it is really an intellectual acrobatics (and forcing) to think of evolution and adaptation of living systems as based on statistical random processes, and indeed also within the mainstream "molecular approach", some clues about the puzzles engendered by this unsatisfying perspective begin to appear (Laursen, 2019). Actually it's much more consistent to consider living matter as a condensate state where the quantum statistical fluctuations, once overcome some thresholds (that are going to be discussed in the next section), break space and time symmetry letting dynamical order to emerge, as also Schrodinger had already argued (Schröedinger, 1944). Now let's turn to which are the physical bases for allowing such features.

2. Theoretical background, a synthesis

In order to proceed into such an analysis of living matter, the first step is to overcome the false distinction between structure and function likewise (and because of) the dynamics of *perception* dissolves right the distinction between a subject and an object because to perceive something means always to perceive how the inner state changed in consequence of the interaction with the perceived (Merleau-Ponty, 1945) (Husserl, 1913), secondly because the dynamics of the emerging of meanings is possible only considering the context "Living system + environment" as an undividable whole (Vitiello G. , 2001).

2.1 Symmetry-breakings and dynamic emergence of order

What that an approach in Quantum Field Theory (QFT) dissolves is right the cartesian dualism (of previous Platonian, and later Aristotelian, heritage) between *structure* and *function*, which in dependence on the contexts, assumes many declinations (for instance: form-substance, information-matter, software-hardware, psyche-soma, soul-body, mind-brain, god-cosmos, and so on…).

In fact, biological matter has the typical ability to be made of somehow long-range correlated components (the same ones as those that are present in the inanimate matter too) but which in the non-living state behave radically a different way. So, by telling things such a way, we could be really tempted to think that the components (several kind of quanta of matter – as molecules, ions, electric charges, atoms – and fields – as electromagnetic fields) are the same ones in one state (living) as in the other (non-living) and that "something" (almost "magical") makes them work in a "special way" as to yield the former *alive*. Actually, as we'll show along this section, this (still vitalistic fashioned) view suffers from a postulate that holds until we keep valid a classical or a semi-classical view of matter (or of what we consider "physical events", in general) where, respectively, the ground (minimum energy) level of a system (even of a single atom) is uniquely determinable (to Classical Physics, CP) or uncertain (within Planck's constant limit) but still unique (to Quantum Mechanics, QM) (Umezawa, 1993), (Blasone, Jizba, & Vitiello, 2011). In fact, in the conceptual framework of QM, a collection of molecules interacting through forces admits, according to the fundamental theorem by von Neumann (von Neumann, 1955), a unique ground state (*vacuum*). Therefore, a unique state (or *phase*) is admitted and phase transitions are not describable (Blasone, Jizba, & Vitiello, 2011). And, on the other hand, an approach by a classical *mean-field*, as used in dynamic systems (Stanley, 1971), is often not enough to take into account certain complex features, like those ones occurring in living organisms (semantics, firstly).

In science of complexity, one of the main (and powerful) tools to describe collective behavior, is Mechanical Statistics[1] (MS) as it revealed very performant even in giving useful answers about complex systems such as neuronal networks. Hopfield, for instance, aiming to understand whether memory stability, and other macroscopic properties of the human brain, could be derived as an emergence starting from collective dynamics, used statistical methods (Hopfield, 1982) which led to great advancements in neural networks design (Amit, 1989), (Mezard, Parisi, & Virasoro, 1987).

However, these methods of analysis, made in terms of classical MS, didn't lead to a substantial understanding of neural cooperation phenomena in the brain because, as a matter of fact, the electric and magnetic fields associated with dendritic currents are too weak to be responsible for the observed massive neural correlation, and on the other hand the spread of chemical agents and neurotransmitters is too slow to explain the observed global and collective activity (Freeman, 2005), (Freeman & Vitiello, 2006), (Freeman & Vitiello, 2008) (Freeman, 2009). And the same problems have been present for long also about the comprehension of other even simpler components and processes in living matter, as: existence of chemical cycles involving biomolecules, biological signaling and bio-communication, biological clocks and synchronization of cardiac cells or of hormonal secretions, spatial organization in morphogenesis and nested topology in organisms.

As we know from abundant literature, a feature characterizing the living dynamics is that of *dissipativity* (Prigogine & Stengers, 1979), (Jørgensen & Svirezhev, 2004), (Vernadsky, 1926), (Del Giudice, Pulselli, & Tiezzi, 2009), (Marchettini, Del Giudice, Voeikov, & Tiezzi, 2010).

The biological system is in fact permanently *coupled* with the external environment; it is an intrinsically *open system*. Isolating it implies the elimination of its functionality, its destruction (its death). As Vitiello has well pointed out (Vitiello G. , 2001), (Vitiello G. , 1998), the thermodynamics accessible today (adequate for isolate or closed systems) requires that in the study of an open system, say the "system α", we proceed to "close" it considering also the environment in which it is immersed, so as to constantly have the balance of flows of matter, energy, etc., between system α and the environment. We can denote the latter as "system β"; focusing on the energy exchange, the energy output from α, $E(\alpha)$, must be equal to that entering β, $E(\beta)$, and vice versa. It must be in any case $E(\alpha) - E(\beta) = 0$. The set (α, β) of systems α and β behaves therefore as a "closed" system, for which there is no energy flow neither input nor output.

For respecting the energy balance (and the balance of flows of every other quantity exchanged between α and β), the system β behaves like a copy of the system α, in the sense that it behaves just like the system α

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[1] Above all in its most advanced versions like the Q-statistics introduced by Constantino Tsallis (Tsallis, Cirto, & Assis, 2014).

regarding the flows, provided that they reverse their verse: in fact, what is an input for α, is an output for β, and vice versa. Clearly, reversing the flow direction is equivalent to exchanging α with β, or vice versa. Since technically the direction of the flow is reversed by changing the sign of the *time* variable, we can say that β behaves like the *copy* of α for which the verse of time has been inverted (β is the *time-reversed copy* of α). In summary, β is the system that describes the environment as regards of the balance of energy flow of α and it is also the mirror image of α in the mirror of time (β is the *time mirror image* of α): Vitiello effectively expressed this fact by saying that β it is the *Double of α* (Vitiello G. , 2001). So, in the case of open systems (as organisms or brains, for instance), we must consider their *doubles*, and this offers some interesting insights.

First of all, provided that α here denotes the considered living system (organism, cell, brain, ecosystem, etc.) and β its thermodynamical *double*, the energy balancing $E(\alpha) - E(\beta) = 0$ is equivalent to the relation $N(\alpha) - N(\beta) = 0$, since $E(\alpha)$ and $E(\beta)$ denote the energies due to the number of quanta[2] involved in the exchange. $N(\alpha)$ and $N(\beta)$ of α and β, respectively, are *condensed*[3] in the fundamental state of (α, β), i.e.; $E(\alpha) = \Omega\, N(\alpha)$ and $E(\beta) = \Omega\, N(\beta)$, with Ω the energy of a single quantum.

This relationship, which describes the energy balance between α and β, is full of meanings. For example, it tells us that $N(\alpha)$ and $N(\beta)$ can certainly vary, provided however that these variations compensate one another. The fundamental state of the whole system (α, β) must be the *condensate* of an equal number of quanta referable to system α and system β, so that the matching $N(\alpha) = N(\beta)$ holds at any time in the history of system α.

Another consequence of the relation $N(\alpha) - N(\beta) = 0$ is that it sets neither the value of $N(\alpha)$ nor that of $N(\beta)$. It only imposes that they are equal. There is therefore an infinity of values for $N(\alpha)$, and correspondingly for $N(\beta)$, for which the relationship is satisfied. In correspondence with these (infinite) values there are equally many fundamental states (*vacua*) of (α, β) indexed by those values of $N(\alpha)$, *orthogonal* to each other (technically they are said to be "*unitarily inequivalent*") (Blasone, Jizba, & Vitiello, 2011) (Vitiello G. , 2001). And the most profound consequence of this fact is that we are compelled to use a theory that – to be truthful – admits infinite fundamental states. Such a theory is right the QFT, and not QM (as we told, because of von Neumann's theorem (Umezawa & Vitiello, 1985).

This it's very interesting in understanding living matter since it is featured by astounding degrees of order, much more complex than the one characterizing a crystal, for instance, and "order" implies that the *symmetry* with respect to time transformations (before/after) and space transformations (translations and rotations, etc.) is broken: here and now it's not equal to there and then. So, when degrees of order appear, a symmetry and an invariance in spacetime are broken (Del Giudice, Doglia, Milani, & Vitiello, 1986).

Therefore, the formation of each configuration (α, β) is made possible through the *breaking of the symmetry* induced by the external stimuli, so that:

(i) the *multiplicity* of the possible configurations is allowed by the existence of the multiple (infinite) possible fundamental states in the scenario offered by the QFT;

(ii) the *coexistence* of such manifold configurations is given by the fact that these fundamental states are orthogonal to each other;

(iii) their *succession* in time is given by dissipative dynamics, i.e.: by its thermodynamical *history*, that is by all the possible couples of values of $N(\alpha)$ and $N(\beta)$ which obey the relationships $N(\alpha) - N(\beta) = 0$.

This shows why, in dealing with living dynamics, it's so important to pay attention to *semantics* and *meaning*: the succession of the states of the system is indeed a time-dependent thermodynamical (dissipative) history along which the following states depends on the previous ones in a deterministic, but *a priori* unpredictable, way because of the presence of its thermodynamical (and semantic) *double* (environment, inclusive of every possible quality and kind of stimuli). From here, we seize that what really matters is the *quality* of the interaction between the living system and the environment and it means that *meaning* is not

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[2] The typology of quanta involved in each case depends on what level of the system we're considering and depends on which the fields mediating the correlations among the components are; in case of biological systems and condensed matter, we deal with electric charges substantially, and a possible good description can be made by considering quanta of matters (electrons, protons, ions, atoms and molecules), quanta of the electromagnetic field and quanta of other kinds (as charge density waves, spin waves, magnetization waves, polarization waves, phonons, dipole waves, etc.).

[3] In a while it will be clear what "condensed" means.

"something" belonging to the stimulus *per se*, but to the *relationships*, or (being closer to a phenomenological perspective (Merleau-Ponty, 1945)) to the *perception* implied in subject-stimulus *dialectics*.

The mechanism of (*spontaneous*) *breakdown of symmetry* provides a key tool in many ambits, firstly in the study of elementary particles and condensed matter physics (Blasone, Jizba, & Vitiello, 2011) (Umezawa, 1993) and reveals the "golden-key" to understand biological systems (Del Giudice, Doglia, Milani, & Vitiello, 1985), (Del Giudice, Doglia, Milani, & Vitiello, 1986) and brain modelling too (Freeman & Vitiello, 2006), (Freeman & Vitiello, 2008), (Vitiello G. , 1995). It is at the root of the dynamics describing systems which display observable, phenomenological, emergent, ordered patterns, for example crystals, magnets – which show spatial order – as well as superfluids, and superconductors – which show order of motion (Preparata G. , QED Coherence in Matter, 1995).

Biological systems show both order in space and order in time, but they produce kind of order which do not necessarily imply repetition (as already E. Schrödinger noticed (1944)), that can configure in "infinitely" many ways thanks to dissipations (i.e.: to coupling to environment); however they are physical systems, therefore they must follow deterministic laws (unless of arbitrary and surreptitious metaphysical discontinuities).

Ordering in motion implies the persistence of a well-defined phase (*phase-locking* or *in-phase* oscillations) in the oscillatory motion of the elementary components. The ordered patterns cannot be derived as the straightforward sum of the properties of the components. For example, the macroscopic magnetization, the electrical properties, the stiffness, etc. are *system*-properties of magnets and crystals not of the individual atomic or molecular components. In order for this to happen, the dynamics of the system components needs *long range correlations*, or non-linearity, among them (Baranger, 2000). Ordering (even spatial order) has thus a *dynamical* origin, and it's not created by forcing each of the components to sit in specific positions or driving their oscillations with a given phase and frequency (externally over-imposed). The range of the correlations, in fact much greater than the typical size of the components (Del Guidice & Vitiello, 2006), dictates indeed the macroscopic size of the system as a *whole*.

In QFT one can show (Umezawa, 1993) that the existence of long-range correlations, and of their associated quanta, the so called Nambu-Goldstone (NG) bosons, is just a consequence of the breakdown of the symmetry characterizing the component interactions. Let's consider, for example, a collection of atoms in a condition such that their positions can be shifted without producing observable changes in the system (i.e.: we have symmetry under spatial translations, that's the case of a gas, or a liquid, or an amorphous). If such a space translational symmetry is broken, so that the atoms can only occupy definite sites at definite distances (multiples of the lattice length), then a long-range correlation arises in the form of an elastic wave connecting the atoms. In such a case the associated NG quantum is called *phonon*. The crystal ordering of the atoms in their lattice sites thus appears as a dynamical effect of the symmetry breakdown: crystal ordering is lack of spatial translational symmetry.

In QFT the dynamics which regulates the behaviour of the elementary components of a physical system as to generate the formation of ordered structures, therefore, has quite general characteristics that can be found in the physics of elementary particles, of condensed matter, as well as in cosmology and in biological systems (Umezawa, 1993) because, in full generality (Pitch, 2017) *order is lack of symmetry*.

The space region of such a correlation – established on a given degree of freedom – is large about as the wavelength of the coupled field mode whose energy seize is equal to the spectral distance between the two levels on which the matter component oscillate in tune, coherently: such a region is called *coherence domain* (CD) (Del Guidice & Vitiello, 2006), (Preparata G. , 1995).

NG bosons exist in the system as fully characterized excitations (quanta), just like the elementary components whose correlations over great distances NG quanta are responsible for. They had been observed through diffusion techniques (using them as targets of particles, for example neutrons, used as probing projectiles) (Wolfe, 1998): if the energetic spectrum is studied by exciting them, inducing deformations in the ordered structure (for example the crystal lattice) by submitting this to external tensions or to thermal jumps, we can observe their corresponding variations of density. The NG quanta then enter themselves in full legitimacy in the list of elementary components of the system, i.e.: NG quanta (the *correlation mediators*) are *structural*. They are an integral part of the *structure*, true and full-rights elementary *components* of the system.

However, they cannot be "extracted" from the system, as can be done for example by extracting an atom or a group of atoms from their lattice sites in a crystal. The quanta of NG are only associated to the state of the crystal. There are no phonons that propagate freely, out of a crystal, and they exist only as long as, if and only if, the crystal exists. Above the melting point of the crystal, only the atoms, constituting the crystal before the fusion occurred, remain, but not the phonons. The latter "are" in fact the *collective way of being of the atoms* in the crystal-state function. Therefore, the *quanta of NG* are identified with the function of the specific *order* for which they are responsible. Without them, the system "is another system", that is: a system with completely different physical properties (or where some of them are missing, just like "that kind of ordering").

In such a vision, *structure* and *function* are thus inextricably linked, entangled, co-substantiated (Vitiello G. , 1998). In physics of condensed systems, it is not possible to establish a distinction between structure and function that makes sense. This distinction, sometimes even with the value of antinomy, dissolves in the dynamics of (spontaneous) symmetry breakings. So, the intrinsically dynamic vision of QFT introduces a *unitary* conception of the *system*, no longer divided between structure and function as happens in the static (classical or corpuscular QM) view, based on the ontological prejudice (see (Renati, 2015), (Vitiello G. , 1998)) of the pre-existence of an isolated structure closed on itself, disconnected from any functional reference. We could point out a key assessment, which reveals unescapable for living matter: *relationship* is the only fundamental ontological *basis* of each represented "part" or "object" and of reality in general which can be intended consistently only as a *relational process* (Renati, 2016).

Now it's clear how *dynamic agents* in complex ordered systems (like biological ones) are responsible for the *emergence* of the *order*. The word "emergence" is often used in various contexts in an ambiguous and qualitative way, leaving wide room for, not always rigorous or consistent, interpretations. In QFT it acquires, instead, a quantitative value and a precise dynamical meaning (Blasone, Jizba, & Vitiello, 2011): the definition of the *phase* of the elementary components such as to correlate them over very large distances, with respect to their dimensions. This correlation is of the same order of magnitude of the system's volume (which compared to the dimensions of the components can be considered infinite). In this way a *correlation wave* is generated whose effect is *to phase* the elementary components (*locking* them in their *in-tune* oscillations): that's right *coherence*.

And, to this new state, a different (lower) energy-level of the ground state (vacuum) of the quanta is associated (properly in a "phase-transition") (Del Guidice & Vitiello, 2006), which implies the thermodynamical stability (and the dissipation of low-order energy – entropy – outside, into the environment (Kurcz, Capolupo, Beige, Del Giudice, & Vitiello, 2010)).

2.2 QED coherence: the emergence of a whole out of the many

Resuming all the QED theory applied to living matter would require too much space for here and I refer the reader to the related literature cited in the following. However, some main aspects will be discussed in this and the next sub-sections:

- the existence of time-dependent states to which work frequencies correspond orchestrating the molecular encounters and the outcoming biochemical pathways (and physiology);
- the establishing of multiplexed phase-couplings of many degrees of coherences in a nested hierarchy (so called "super-coherence");
- the fact that such a *choir* of frequencies is ruled by fractal dynamics which allow the coupling and uncoupling of the several levels among each other only when necessary in order to transfer energy on demand from local to global and vice versa;
- the possibility to modulate these couplings thanks to the special energetic spectrum of the water molecules participating to the coherent dynamics and to the special "connective" water matrix in living systems.

Once this done, we can proceed to discuss how semantics may emerge and what it could physically mean.

According to a QED approach, living matter is conceivable as a super-coherent water-based matrix, where water occupies more than 90% of the molar fraction (Del Giudice, et al., 2005). The condensed phase of water in living matter enjoys special conditions due to the ubiquitous presence of interfaces and niches which further stabilize the coherent domains of water, with respect to the ordinary liquid bulk where it would be less than 50% at room temperature (at 1 atmosphere) (Del Giudice, Stefanini, Tedeschi, & Vitiello, 2011), (Del Giudice & Tedeschi, 2009) (Del Giudice, Spinetti, & Tedeschi, 2012). That's why it has a sol-gel state and living matter is somehow "solid" (Ling G. , 2012) (Ling G. , 2001).

The condensation of matter into coherence domains is a spontaneous -symmetry breaking which occurs above a density threshold (and below a critical temperature), like the condensation discussed above about (phonons in crystals, magnons in ferromagnetic materials, and the correlations in superconductors and superfluid Helium) (Blasone, Jizba, & Vitiello, 2011). For water, such thresholds are about 0.32 gr/cm^3 and 373,15 K (at 1 atmosphere of pressure) (Bono, Del Giudice, Gamberale, & Henry, 2012).

Within biological matter the size of the various kinds of coherent domains which can be established (on several degrees of freedom, as: electron cloud oscillations over several possible excited levels, dipole rotations, ortho-para spin fluctuations, and many others related just to the water molecule) is never smaller than the maximum distance between whichever surface (membrane, molecular backbone, etc) and another (Del Giudice, et al., 2005). Therefore, all the water matrix in living matter experiences a multi-modal coherence (super-coherence) which, together with all the other coherences (established on other molecular species, structures and degrees of freedom), allows a general phase-correlation all over the system (whether it is a single cell or a pluricellular organism) (Del Giudice, Stefanini, Tedeschi, & Vitiello, 2011) (Del Giudice, Doglia, Milani, & Vitiello, 1985).

As it will be discussed in the following, it is just this global sharing of the eigenstates of the phase which allows an emergent dynamic stability, and the appearing of a biological "self" which, nonetheless, cannot be established but on unceasing flows, oscillation cycles and dissipation of entropy. This dynamicity requires us to think of the living being not as a physical "object" but as an *open process*, like a vortex in the river: to distinguish it from the water does make no sense (Ho, et al., 2006) (Ho M.-W. , 2012) (Del Giudice, Pulselli, & Tiezzi, 2009) (Vitiello G. , 1998), (Freeman, 2009).

This is an extreme synthesis of a vast theoretical background which cannot be resumed here (and for the deepening of it we address to the cited literature), also because the scope of the present work is not to review wholly such a theoretical background, but spotting out its final most remarkable consequences, useful to review what can be retrieved by the "complex picture" engendered by the a symmetry-braking and field-view of living matter.

However, before going on into the other key-points of the theoretical picture offered by an approach which composes the suggestions given by QED, open system TD, fractals, symmetry breakings, we mention the most salient aspects annexed to the coherence in water, since necessary to understand the physical meaning of "responding" (different from "reacting") and the physical roots of the time-dependent coupling to the environment.

More and more experimental evidences (Renati, Kovacs, De Ninno, & Tsenkova, 2019), (Tokushima, et al., 2008), (Huang, et al., 2009), (Taschin, Bartolini, Eramo, Righini, & Torre, 2013) and descriptive approaches (Wikfeldt, Nilsson, & Pettersson, 2011) have been showing liquid water as a bi-phasic system where, according to QED (Preparata G. , QED Coherence in Matter, 1995), a fraction of molecules (whose abundance is inversely related to the temperature) is organised into collective, coherent, oscillations within regions large about as the wavelength of the coupled electromagnetic mode whose energy seize is equal to the spectral distance between the two levels on which the electron of each water molecule oscillates in this dynamics. Like we told above, in section 2.1, such regions are called Coherence Domains (CDs) and, for liquid water, coherence being established between sp^3 and 5d levels, their theoretical size (i.e.: neglecting the effect of non-zero temperatures) is ideally about 100 nm. Actually at temperature different from zero Kelvin, this size is reduced by thermal noise, which sets out of tune a fraction of molecule (constituting the incoherent, vapour-like, part of the system) (Arani, Bono, Del Giudice, & Preparata, 1995) (Bono, Del Giudice, Gamberale, & Henry, 2012).

The molecules belonging to the coherent fraction constitute an ensemble where the phase is the well-defined quantum observable: their common wavefunction is defined by eigenstates of the phase, complementary observable to the "number" operator. Thus, in the coherent state the number of oscillators become completely uncertain, while the phase, the wave aspect of such a "classical" (since stable) field is sharply defined. This imply that in a coherent state the individuality (and countability) of the oscillator loses any physical meaning, since a field of uncountable quanta (in this case a matter-field, coupled to an electromagnetic field) is the only possible definable object (Preparata G. , 1995). The new ground state, associated to the coherent molecules, is lower than the one of incoherent, isolate molecules. The difference of this energy is called *energy gap* and expresses the thermodynamic stability of the coherent state against decohering agents from outside (like temperature, photons, fields in general and mechanical forces). If the excitations are small enough (smaller than the energy gap) the CD receives them as a whole, if they are bigger a one or more oscillators will be set out of coherence and "poured back" int the normal (incoherent) fraction. (Arani, Bono, Del Giudice, & Preparata, 1995) (Preparata G. , QED Coherence in Matter, 1995). For ordinary liquid water – where coherence is established on the electron cloud oscillation for each molecule – this energy gap is of the order of 0.2 eV (depending on the temperature and the position inside the CD (in the periphery is smaller than in the centre, of course) (Bono, Del Giudice, Gamberale, & Henry, 2012).

When the liquid is confined or hydrophilic surfaces are available, the coherent fraction gets stabilized and possibly other degrees of coherence (as the dipole rotation) can be settled. This is the typical condition in living matter as specified in the following (Pollack, Yoo, & Paranji, 2011) (Pollack, Zheng, Chin, Khijniak, & Khijniak, 2006).

The dynamical regime where coherence is established does not require, in general, the presence of an externally supplied cavity and a pump (as, on the contrary, it happens in laser physics) and water CDs are self-produced cavities, where a self-trapped electromagnetic field cannot be irradiated externally being subjected to a coupling with molecules which implies total internal reflectance (Arani, Bono, Del Giudice, & Preparata, 1995), (Preparata, Del Giudce, & Vitiello, 1988).

The coherent oscillation of the CDs in liquid water involves the 5d orbital as the selected level whose weight in the coherent state is 0.13, thus each molecule participating to the coherent dynamics gets endowed with one electron that spends 13% of its time at 5d energy level, 12.07 eV above the sp^3 hybrid orbital (without considering the collective electron storable excitations, see the following). This level is at most 0.53 eV below the ionization threshold (I_{th}), located at 12.60 eV. Thus, it is like to say that there are 0.13 quasi-free electrons per coherent molecule. In a CD there are about seven million molecules so that we have about $6 \div 9 \cdot 10^5$ quasi-free electrons per CD.

These quasi-free electrons can also exit out of the CD by quantum tunnel effect toward suitable partners (as the oxygen molecule, or non-coherent water molecules, or other species) or could be extracted by small excitations (Del Giudice, et al., 2005). When the electron is extracted from the CD, it leaves behind an ionised molecule, which, having lost an electron, cannot join any longer the coherent oscillation and therefore reaches the non-coherent fraction of molecules that includes, as in the Landau model of liquid Helium, the molecules put out of tune by thermal collisions (Arani, Bono, Del Giudice, & Preparata, 1995). The extracted electron could be captured by an oxygen molecule dissolved in water giving rise to a negative ion. The pair of ions so produced, after some chemical steps (Voeikov & Del Giudice, 2009), gives rise eventually to a proton and a hydroxyl. The CD is therefore a *donor* of electrons and then a chemical *reducer* that, together with the non-coherent fraction, forms a *redox pile* (Del Giudice, Stefanini, Tedeschi, & Vitiello, 2011) (Germano, Tontodonato, Hison, Cirillo, & Tuccinardi, 2011), (Voeikov & Del Giudice, 2009).

Water CDs being easily excitable, are able to collect many small external excitations (high entropy energy) producing unique coherent vortices whose energy is the sum of all the small collected energy excitations, but whose entropy is small (high grade, low entropy energy) (Del Giudice, Spinetti, & Tedeschi, 2012). This collective energy, however, cannot be released outwards in a thermal way and this explains the long lifetime of the coherent excited states within the domains – told for this reason *cold vortexes* – and in living matter too, like A. Szent-Gyorgyi guessed decades ago (Szent-Györgyi, 1941a) (Szent-Györgyi, 1957).

In order to produce in turn coherence among CDs, it is necessary to make them oscillate, which means that in a part of the oscillation cycle, the CDs should be able to discharge energy outwards, and in the other part of the oscillation cycle should re-gain it from outside excitations (Marchettini, Del Giudice, Voeikov, & Tiezzi, 2010), (Del Giudice, Spinetti, & Tedeschi, 2012) (Del Giudice, Stefanini, Tedeschi, & Vitiello, 2011).

To do that, a possibility is releasing quanta of energy to molecular excitable species able to match some their oscillations modes (energy excited states) which match with the energy released by the water domains. In this case a chemical exploit of the received energy could occur, as the excited (activated) molecular species could (more easily) participate as reagents in chemical and electrochemical reactions (Del Giudice, Stefanini, Tedeschi, & Vitiello, 2011).

Therefore if external non-aqueous molecules, present in the liquid, contain in their own spectrum at least one frequency close to the oscillation frequency of the water CD (resonance), then these molecules could participate to the coherent dynamics of the liquid and would be subjected to some dynamics we now sketch out synthetically (Del Giudice, et al., 2005).

In bulk liquid water, solute species are in general confined in the non-coherent fraction of water placed where the decaying tails of the trapped electromagnetic fields overlap each other between CDs. Therefore, the interface regions are the crucial ones where interesting phenomena occur. The point is whether the other guested molecules, located among the CDs of water, possess in their spectrum oscillation modes very close / equal in frequency with those ones of the solvent CDs or not. If yes, and this is what makes a meaningful difference in living matter, the "guested" other molecular species (or super-structures as proteins, membranes, etc) are able to share some of their oscillations with some of the possible modes of water molecule (or of water CDs). In this case they could resonate and, seemingly to water molecules they would be attracted to the CDs, getting stuck on their surface (or even building up new substrates to which other domains are stabilized too). If this occurs, the guest molecules become part of the coherent dynamics. This, has deep consequences for both chemical pathways and topology of the structures in living matter (Del Giudice, Doglia, Milani, & Vitiello, 1985) (Del Giudice, Doglia, Milani, & Vitiello, 1986) (Del Giudice, Spinetti, & Tedeschi, 2012).

Within cells a huge number of chemical reactions occurs with well-defined time sequences without mistakes and at rates much higher than *in vitro*. The high rate and absence of mistakes imply that the underlying chemical dynamics should not be based on random collision but on the mutual long range attraction of the molecules in a selective way (Del Giudice & Tedeschi, 2009), (Ho M.-W. , 2008) according to specific organic codes (Barbieri, 2004)

The existence of the collective coherent electron vortex levels between the *5d* and the I_{Th}, and their ability to work as a storing device for the energy collected by the CD, tells us that the proper frequency of the CDs of water can be widely (about 0.4 eV span) and ultra-finely (few tens of kHz steps) modulated, getting tuned to the modes of many chemical species and systems in general (Del Giudice, et al., 2005)

This is a crucial point, in fact, by adding to this the consequences of the exponential decaying of the electromagnetic field at the CD interface, we got the key to understand how chemical reactions, assisted by coherent water, can be dramatically different than those conceivable by thinking of water as a mere passive solvent with no active role in the chosen pathways. The self-trapping of the electromagnetic potential inside the CDs produces strong gradients at the interface, to which the production of forces is associated (Tedeschi, 2010), (Del Giudice, et al., 2005). These forces, according to the laws of electrodynamics, are developed into two contributions: one electrostatic (independent of the frequency) (Eq. 2.2.1), the other electro-dynamic (dependent on the frequency) (Eq. 2.2.2, Eq. 2.2.3), if C is a constant, we have:

$$\boldsymbol{F}_{rep} = -\frac{q^2}{M}\boldsymbol{\nabla}\boldsymbol{A}^2 \approx qV\ (V = 0.1\, Volt) \qquad \text{(Eq. 2.2.1),}$$

$$\boldsymbol{F}_{i-CD} = C\,\frac{(\omega_{CD}^2 - \omega_i^2)}{(\omega_{CD}^2 - \omega_i^2)^2 + \Gamma^2}\boldsymbol{\nabla}(\boldsymbol{A}^2) \qquad \text{(Eq. 2.2.2),}$$

$$\boldsymbol{F}_{int\,1-2} = C\,\frac{(\omega_1^2 - \omega_2^2)}{[(\omega_1^2 - \omega_0^2)^2 - (\omega_2^2 - \omega_0^2)^2] + \Gamma^2}\boldsymbol{\nabla}(\boldsymbol{A}^2) \qquad \text{(Eq. 2.2.3).}$$

With: C a constant, q the electric charge, m the mas of the electric charge, $\boldsymbol{A}$ the quadrivector potential of electromagnetic field, $\boldsymbol{\nabla}$ the Nabla operator, ω_0 the pulsation (radial frequency) of the field, $\omega_{1,2,\ldots n}$ the pulsations of the 1^{st}, 2^{nd}, $\ldots n^{th}$ species, respectively, in the field, Γ the damping factor

The relation (Eq. 2.2.1) (expressing the ponderomotive force) tells us that any electrical charge (independently of its sign) at the surface of a CD is repulsed outwards with a force proportional to the ratio q^2/m. This, indeed, it's what occurs to the electron of the cold vortexes which are thus necessarily confined at the external surface. Electrons, being about 2000 time lighter than protons, are forced outwards much more intensely so a strong polarization is induced in molecules and atoms attracted on the CD surface, because the static force is always repulsive (both for positive and negative charges) and depends on the charge-to-mass ratio: this means that electrons (lighter) are expelled much more externally than nuclei (heavier) and the molecules result strongly polarized and thus chemically more reactive (Del Giudice, et al., 2005).

The (Eq. 2.2.2) expresses how the interaction force between a CD and an atomic/molecular species (made of electric charges, though not necessarily bearing a net charge, it can be also neutral) depends on the oscillation modes of both. Otherwise said: if a species has one mode of oscillation whose frequency is very close to the frequency of the CD, it is selectively subjected to a diverging force (typically attractive) increasing with the vanishing of the frequency difference. The more a proper frequency of a species is close to the frequency of the CD and the more that species is sharply selected being subjected to the developed force vector: that force can be both attractive and repulsive in dependence on the algebraic sign of the difference in frequency between CD and the molecule. Extremely fine tunings in CD frequency can cause that those molecules which before were attracted to it now can be repulsed faraway. The (Eq. 2.2.3) describe, according to the same dynamics, the force of attraction / repulsion among two species in dependence on their frequency matching in the background field of the CD oscillating at ω_0 (Del Giudice, et al., 2005) (Del Giudice, Spinetti, & Tedeschi, 2012).

The frequency ω_0 we're speaking about is the one of the quasi-free electrons in the CD which correspond to the renormalized frequency of the field whose energy size is given by the chosen level placed somewhere between the $5d$ orbital (included) and the I_{th}, in the "continuum" band available for the cold vortexes (Bono, Del Giudice, Gamberale, & Henry, 2012).

To provide some more detail, the first step to establish *super-coherence* occurs when a large set of CDs get excited (storing energy by collecting external inputs both mechanical and electromagnetic) and relax, by releasing free energy (because thermal relaxation is forbidden) to some "acceptors" (typically: other species which are allowed to populate excited levels by acquiring the right amount of energy released by one or few relaxing CDs). This oscillation cycles are, of course, established on much smaller energy sizes (those pertaining to the energy differences among the collective quasi-free electrons bands) than the first step which gives rise to CDs established among the electron cloud of millions of water molecules.

The creation of other collective coherent oscillations can occur on many other degrees of freedom (to which specific energy gaps, frequencies, wavelength correspond) giving rise to a vast array of tangled cycles.

Of course, *super-coherence* is realized only in specific conditions are satisfied (typically in living matter) because, in general, the proper frequency differences between the guest molecules and those of water molecules could, in principle, disrupt the total coherence, unless the number of guests is very small with respect to the number of water molecules or unless these "alien" species have modes really close / identical to the ones of CDs. By recalling a metaphor by E. Del Giudice et al. (Del Giudice, Spinetti, & Tedeschi, 2012): «a dozen of singers chanting a different tune even loudly would not disturb a chorus of one thousand loud singing children, but would be a nuisance in a chorus of, say, fifty children». This consideration could help us to understand the so large abundance of water within a living organism (more than 90% of the total number of molecules). It's possible that the CDs would be unable to govern (i.e.: to keep in resonance, phase-locked) number of guest molecules larger than such a little numerical fraction (Bono, Del Giudice, Gamberale, & Henry, 2012) (Del Giudice, Spinetti, & Tedeschi, 2012).

Therefore, if a small number of guest molecules is allowed to participate to the resonance and get stuck to the CDs, then the excitation energy stored in the CDs could be available also to the formers giving place to the charge-discharge cycles of CDs: a new step of (spatially larger and temporally slower) coherence, nesting inside itself the (faster and shorter) one occurring among molecules gathering in CDs. When the amount of stored energy matches the activation energy of the molecules, it would be transferred to latters, simultaneously producing (i) their chemical activation, (ii) the energy discharge of the CD and a (iii) chemical reaction array, because this imply time-ordered changes in the frequency of the collective motion of the quasi-free electrons of the CD, which becomes able to resonate with different species at each step of exchange (when a net charge, a molecule, a photon or a quantum of angular momentum of cold vortexes, etc. are modified). It's has been thus correctly argued that CDs of water would then behave as a *multimode laser* (Preparata, Del Giudce, & Vitiello, 1988), (Arani, Bono, Del Giudice, & Preparata, 1995), (Bono, Del Giudice, Gamberale, & Henry, 2012).

Important consequences arise from these dialectics between the frequency of the self-trapped electromagnetic mode and the partnership with other molecular species (or structures). We resume them from reference (Del Giudice, Spinetti, & Tedeschi, 2012):

a) The CD has completed an oscillation, whose duration depends on (i) the rate of energy storage ($\Delta t \sim \hbar/\Delta E$), on (ii) the height of the required activation potential (for example the potential barrier experienced by electrons to be transferred to a partner molecules) and on (iii) the rate of a chemical reaction or of another process (as elastic deformation of a molecular chain, of a protein, or of a membrane, or transferring momentum to orbiting ions around water domains (Del Giudice, et al., 2005)). The inverse of this time is the frequency of oscillation of the CD (as a whole) in the cycle where energy is exchanged with other partners. Provided that many neighbouring CDs are in the same chemical and thermodynamic environment/conditions, they could enter a collective coherent oscillation that would in turn increase the degree of coherence (that is: the width of the coherent oscillation and the amplitude of the protective energy gap) of each participant CD (Del Giudice, Spinetti, & Tedeschi, 2012).

b) The chemical reactions, which occur on the surfaces of CDs and which benefit also from the electron transfer available there, are no longer conceivable as governed by diffusion but by a frequency-based electro-dynamic long-range selection. According to the (Eq. 2.2.3), two molecules oscillating with frequencies ω_1 and ω_2 within a region filled by an electromagnetic field oscillating with a frequency ω_0 develop a very long-range and strong attraction when the three frequencies coincide. This long-range attraction replaces diffusion as the molecule interaction agent. The existence of codes and maintained cycles governing the array of biochemical reactions in cells can therefore be understood now (Del Giudice, Stefanini, Tedeschi, & Vitiello, 2011) (Voeikov & Del Giudice, 2009).

c) The energy output of the chemical reactions is released, because of coherence, as an excitation of the electromagnetic field trapped in the CD or as a released charge (typically electrons or hydroniums/protons) with an associated momentum depending on the orbital motion in the coherent cold vortexes (Del Giudice, et al., 2005). When energy is exchanged by releasing/absorbing photons or charges (or even molecules) a corresponding shift of the CD frequency is produced, changing in turn the resonance conditions, i.e.: changing the molecular species able to be attracted now and opening consequently a new (bio)chemical step (possibly part of a cycle). Each chemical step is therefore launched by the outcome of the previous one. The possibility of an ordered array of (bio)chemical reactions emerges.

This last point plays a crucial role in biological functioning, as it's obvious: it's the first physical consistent explanation of how in the cytosol or in the extra-cellular matrix reactants can be "convened" at the right moment and at the right place in a cyclic (possibly autopoietic) reaction path, without creating spurious products and without the slow timing implied in diffusion as often conceived by the mainstream biochemistry (Berg, Tymoczko, & Stryer, 2006), (Baserga, 2008).That's why biological systems have such a high energetic yield with respect to thermodynamic machines. Coherence can support an ordered functioning where system is able to evolve by changing its own work-frequencies not randomly: coherence is the basis for the seven fundamental characteristics of life: (1) ordered cell structure, (2) reproduction, (3) growth and development, (4) energy utilization, (5) response to the environment, (6) homeostasis, and (7) evolutionary adaptation (Campbell & Reece, 2002)

More precisely: this last point is the basis to ground physically the dynamics of *response* (and the emergence of *meaning*) much more "integrated" than a reaction (straightforwardly predictable by Newton's laws, where the outcomes depends on *quantitative* variable as forces, momentum, energy, electric charge, net magnetic flux, current, etc.), we return on this point in the next section.

Chemical interaction, changing the nature of the actors (the CDs), modifies the nature of the (oscillatory) background at each step, in time; new frequencies of the electromagnetic field emerge while the previous ones disappear (thus a chemical-physical *history* unfolds). Since the opposite dependence also exists, the set of modes of the electromagnetic field, each characterized by a certain frequency that governs the chemical evolution of the system, is in turn modified by the chemical reactions that change the nature of the components of the considered system. The time-dependent set of working frequencies of a given system constitutes its "identity", its specificity, its "law of existence", and its non-random "evolutionary path", given some thermodynamic and electrodynamic boundary conditions.

This is the point to understand that: a coherent system is able to give responses to any inputs (if able not to destroy the coherence of the system itself, because too "intense" chemically, mechanically, thermally, electromagnetically, etc) which are ruled just by the coupling with the environment and the *history* of the system itself. i.e.: the array of states undertaken till now, which non randomly, succeeded to one another and determine each step the new coherent holonomic state of the system. The state assumed at each step is not reducibly determinable by action-reaction dynamic laws and pertains always to the *configuration* of the whole <system + environment>. This dependence on the configuration and states involved along the history of system as a whole (since all oscillators, on several degrees of freedom, share eigenstates of the phase) are the basis for the emergence of a *self* and of a *qualitative* feature deeply implied in the <system-stimuli> physical relationship. I'm proposing that this is the "seed" for the emergence of a *semantic* aptitude in living matter, thought of as the quality of the physics-based *configuration* given by «the eigenstate of the system coupled to the environment» (with "environment" also the inner of the living system has to be considered, see section 3).

2.3 Living matter is based on nested cycles

It's important to remark that the principal features we resumed related to coherence and super-coherence in living matter, transduce into 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 tissues, organs and the whole organism. Evidences, indeed, had been collected showing how the structures in living matter (in dimension and topology) could be actually due to its distribution in dependence on the spatial interference patterns of electromagnetic field standing waves in a watery medium (Pietak, 2011), (Cifra, Havelka, & Deriu, 2011), (Pietak, 2012). This phenomenon, in mechanical and sound waves, is also known as *cymatics* (Misseroni, 2016), (Oh & Kim, 2012) which in essence consists in the study about how matter is patterned in space by fields. Such fields actually may be sound or electromagnetic waves, in this second case, the well-known dielectrophoretic effect is at work, related to the different ponderomotive forces developed by time-varying fields on particles in dependence on the frequency, amplitude and wave-shape of the formers, and on the dielectric constant and the shape of the latters (Pohl, 1978); these variables are related in the well-known Clausius-Mossotti relation (Van Rysselberghe, 1932).

Actually these two aspects – compartmentation and cycles – are two faces of the same coin and are the focus for understanding the extra-ordinary thermodynamics of living systems. Coherent oscillations, of course constitute work cycles and this oscillations spans over spatial ranges which have the order of magnitude of the wavelength of the electromagnetic coupled mode, and their time-scales are of the order of magnitude of the inverse of their frequency (Del Giudice, Doglia, Milani, & Vitiello, 1986) (Del Giudice, Pulselli, & Tiezzi, 2009) (Blasone, Jizba, & Vitiello, 2011) (Ho M.-W. , 2013). This implies the building of compartmentations and matter structures whose topology is dictated by the electromagnetic potential gradients (and forces, described in Eq. 2.2.1-3) (Del Giudice, Doglia, Milani, & Vitiello, 1985), (Del Giudice, Doglia, Milani, & Vitiello, 1986). In particular, 2D (membranes and sheets) and 1D (chains and filaments) structures had been shown to be the result of electric and magnetic fields self-focusing associated to the of Anderson-Higgs-Kibble mechanism (Kibble, 1976), (Kibble, 1980), (Vilenkin, 1985), (Anderson, 1958).

The several possible degrees of freedom (modes) on which coherence establishes pertain to different typical space-time scales dictated essentially by the wavelength and the resonance frequency of the coherent electromagnetic modes (as well as phononic modes and other kind of correlations outcoming by symmetry breakings (Blasone, Jizba, & Vitiello, 2011)) coupled to the respectively co-dimensioned matter domains. Coherence itself is made of cyclic dynamics because it means oscillation in phase of the matter components among two or more energy levels.

Biologists have been puzzled for long about why biological activities are predominantly rhythmic or cyclic, and much effort has gone in vain into identifying some 'centre of control', and more recently to recognise "master genes" that control biological rhythms (Davis & Rebay, 2017). Actually each organism, even the simplest one, is dictated and characterized by a big amount of cycles with periods ranging from pico and nanoseconds (for collective electrons oscillations), up to microseconds and milliseconds for work cycles of "molecular machines" (McClare, 1971) which perform bio(electro)chemical work, up to circadian, tidal, seasonal, etc. and circa-annual cycles of whole organisms and populations of organisms or ecosystems (Brizhik, Del Giudice, Jørgensen, Marchettini, & Tiezzi, 2009), (Del Giudice, Pulselli, & Tiezzi, 2009).

Here, I won't deepen the vast topic of TD in living systems (for which I address the reader to Onsager (Onsager, 1931), Morowitz (Morowitz, 1968), Ho and Ulanowicz (Ho M.-W. , 2013), (Neidhardt, 1996), Prigogine and Stengers (Prigogine & Stengers, 1979), Jørgensen and Svirezhev (Jørgensen & Svirezhev, 2004), but I just want to list out some key topics about cycles and their role in the energy mobilization (which to us is important for understanding physically the dynamics of *response*).

Prigogine's "dissipative structures" had been suggested to be possibly the origin of dynamic organisation in living systems (Prigogine I. , 1954). All we know, the most simple and prototypical dissipative structure is given by the Bénard-Raleigh cells that appear in a shallow pan of water (or other more viscous liquids as paraffine) heated perfectly uniformly from below (Bénard, 1900). At a critical temperature difference between the cold top surface and the hot bottom, a dynamical phase transition occurs: the lighter warmer fluid rises to the top while the denser colder one sinks, giving an ordered pattern of convection cells that look like a honeycomb if watched from the top. Prigogine emphasized energy flow and dissipation to be the active agents in the phase transition to collective behaviour that makes the 'dissipative structure', but the phenomenon depends on the liquid being able to absorb and store the heat energy, and to expand: actually it depends on the formation of a *cycle*.

Indeed, in order to benefit from energy flow, the system must capture and store the energy to lift it up from thermodynamic equilibrium, at which nothing could occur. Similarly, solar energy flows through other planets as through the Earth, but only earth can capture the energy by means of water in oceans and atmosphere (before living organisms appeared) and by means of the chlorophyll of green plants to support most of the biosphere, which is one big energy store maintained far away from thermodynamic equilibrium. The key to understanding the thermodynamics of organisms is, therefore, not energy flow or mere energy dissipation, but *energy storage* under *energy flow* (Ho & Ulanowicz, 2005) (Ho M.-W. , 2013).

Energy flow is of no consequence unless the energy is trapped within the system where it circulates, to do work and to build up structures for storing the energy before it is dissipated. 'Dissipative structures' is still a not appropriate notation for what living 'energy storage structures' really are (Ho M.-W. , 2008). 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;
- these cycles are many, nested and interwoven one another (see details in the following).

Within cycles, energy is mobilized and, right for this, it remains largely stored. The energy goes into complex cascades of coupled cyclic processes within the system before it dissipates to the outside. These cascades of cycles span the entire range of space-time scales from slow to fast, from local to global, that all together make up the *life cycle*. An intuitive representation of this has been given by Mae-Wan Ho (Ho M.-W. , 2013, p. 35).

The cycles and the consequent compartmented structure of each living system are the true requisite for the high TD yield and the astounding energy management. Indeed, it is commonly ascertained that the organism is an open system whose organization is maintained in some kind of 'steady state' by a flow of energy and chemicals and that as soon as that flow is interrupted, disintegration sets in and death occurs. That steady state, however, is not a static bulky (thermodynamic) homogeneous phase in a rigid container (like for the Bénard cells in water inside the heated pan). Well far from it, within the organism, one finds organized heterogeneities or dynamic structures on all scales. There is no homogeneity, nor static portion held at any level. Within a living body, there are organs, tissues and cells, vesicles, pockets, niches, ducts, intramolecular sites, etc. each with a certain degree of autonomy and closure (Ho, et al., 1996) (Ho, et al., 2006).

Spatially, the cell is partitioned into numerous compartments by cellular membrane stacks and organelles, each with its own 'steady states' of processes that can respond directly to 'external' stimuli and release signals to other compartments. It's necessary to put '*external*' between quotation marks because, in the nested structure of the organism, the environment of a small compartment is enclosed within a larger one, which is in turn enclosed by a more inclusive domain, and so on[4] (Ho, et al., 2006) (Ho M.-W. , 2008). And within the smallest compartment, 'microdomains' with no clear-cut barriers can be separately energized to give local circuits; and complexes of two or more molecules can function as 'molecular devices' that can cycle autonomously without immediate reference to its surroundings doing different things: transcribing genes, assembling proteins, 'pumping' ions, extracting energy from food, etc., all working within confined (nano) spaces. More importantly, the activities in all those compartments, from the microscopic to the macroscopic are perfectly orchestrated, which is why the organism looks like a dynamic super-coherent liquid crystal (Ho, et al., 2006).

To maintain a high thermodynamic yield, even more important than *space* closure is *dynamic* (time) *closure*, which enables the organism to store as much energy and material as possible, and to use energy and matter most efficiently in cycles, i.e., with the least waste and dissipation. In other words, the steady 'state' is not a single state defined by unique "encompassing" state functions at all, but a conglomeration of space-temporally organized processes. The organism has an inherent space-time structure (Li, 1992a) (Li, 1994) and cannot be represented as an "instantaneous-average state" in the sense that, if thermodynamics were to apply to living systems, it must apply at each level time by time, ultimately, even to individual molecules, and not just to statistical ensembles of molecules (McClare, 1971) (Ho M.-W. , 2012).

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[4] We'll see that this feature is the one which, extended to larger space-times scales, allow us to achieve a new encompassing definition of ecosystem.

In this regard, a need to "reformulate of the Second Law of thermodynamics" had been claimed (Ho M.-W. , 2013, p. 35): in order to formulate the second law of thermodynamics so that it applies to single molecules, McClare firstly introduced the important notion of a *characteristic time interval (time scale)*, τ, within which a system reaches equilibrium at a temperature θ (McClare, 1971). 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 remain in a non-equilibrium distribution, within a time interval $t_s > \tau$, either localized within the system, or such that the states of higher energy are more populated than the states of lower energy for the temperature θ.

The paramount form of stored energy is right coherent energy releasable by any kind of domain. So, stored energy is any form that does not equilibrate, or degrade into heat in the interval τ. As said above about coherences a typical time scale of relaxation is in fact a space-time scale associable to a given level of compartmentation, which has its own space-time scale. Thus, McClare restated the second law somehow as follows: useful work is only done by a molecular system when one form of stored energy is converted into another (McClare, 1971). In other words, thermalized energy is deemed as unavailable for work and it is impossible to convert thermal energy into stored energy.

The immediate objection (Ho M.-W. , 2013, p. 36) to this formulation is that, in general, it is wrong. Indeed, the engine of a car depends right on thermalized energy: work is extracted out of the thermal energy of combustion. McClare was right to stress that useful work can be done by a molecular system via a direct transfer of stored energy without thermalization. The process of photosynthesis, on which most of life on earth depends, involves the direct, non-thermal absorption of the energy of photons, which is why typical thermodynamic calculations based on the temperature of the sun may be irrelevant, (Voeikov & Del Giudice, 2009). But what is needed to enter the play is right considering the characteristic space-time scale of the structure / cycles where energy is release and/or stored.

Of course, non-thermal energy transfer is the rule in living processes. However, energy can be directed or channelled to do useful work in a cooperative system, as in the case of molecular devices embedded in a membrane across which a very high electric potential is settled (which in fact is a form of stored energy able to act as a Maxwell's demon (McClare, 1971)).

The most important thing is that: in a system with space-time organization, 'thermal' (rich in mircostates) energy in (and for) a small compartment is still *stored* energy within a larger compartment encompassing. This is true because the time scales of successive larger levels of compartmentation are longer than the sub-levels.

And this emerges clearly by taking account of coherence where oscillations occur. Each level of coherence has its own size (its space scale, given about by the wavelength, λ, of the involved electromagnetic mode) and its own time scale (given about by the resonance frequency of that mode, ω_r). So the characteristic time, τ, suggested firstly by MacClare could be estimated 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, 2014)) and on the other hand molecular dipole rotation (wavelength up to $\lambda \approx 500$ μm, resonance frequency $\omega_r \approx 5 \cdot 10^{11}$ Hz and energy gap $\Delta_g \approx 0.02$ eV in the bulk, possibly increased when interfacial conditions are considered (Yinnon, Elia, Napoli, Germano, & Liu, 2016)). The microstates released from the first level, if enough "mild" (in order not to set out of coherence the components in the second level of hierarchy) represent still ordered (stored) energy for the second (larger, slower) level.

Mae wan Ho (Ho M.-W. , 2008) very keenly proposed that a more adequate restatement of the second law 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.*

This refined version by Mae-wan Ho offers a way of defining a 'system' in terms of the extent of thermal equilibration in a characteristic space-time. Thus, the motorcar works on thermalized energy from the combustion engine because the piston is doing work externally onto the system containing the thermalized energies of the expanding gases generated from the combustion.

From the explicit introduction of time-scale, and hence of space-time structure, two quite distinct ways of doing useful work most efficiently do appear: not only slowly (i.e. at equilibrium) according to conventional thermodynamics, but also fast; both of which are reversible and at maximum efficiency since ideally no entropy is generated within that space-time compartment (Ho & Ulanowicz, 2005), (Morowitz, 1968). Of course “slow” or “fast” are meant relatively to the timescale, τ, of the considered nested space-time domain (and cycle).

A “fast” process is, for instance, the releasing of a photon from a site and its adsorption by another structure having comparable times of relaxation; or a charge transfer to a molecule whose chape change occurs in consequence and at a speed implying durations of the order of the excited state associated to the presence of a net charge.

A “slow” process is one that occurs at a rate matching (or slower than) the time required for all exchanging energies to equilibrate or distribute themselves over the whole larger system. Think, for instance, of the mechanical energy – work –given by the translation of the piston in the engine while the microstates of the expanding gases are entropically thermalizing: the entropy increases at the level of microstates thermalizing at the molecular scale of the gas, but at the next, larger, level of the piston it is transduced into work, because the characteristic space-time scales of the latter is much slower-larger than the one of the gas microstates. As we can see, compartmentation and closure are crucial to allow such an energy exploitation from a level to another.

Thus, the manifold of nested characteristic space-time scales of the organized compartmented structures allow energy exchanges among the several levels both through slow and fast way (because the energy which would thermalize at a given small scale, is still exploitable as ordered energy at a larger level)[5].

The amount of energy stored in the organism is huge because is huge the amount of structuring. Energy is stored in complex chemical molecules, in macromolecular conformational fluctuations, concentration gradients across membranes, in electric fields created by charge separation, in viscoelastic fields – due to mechanical strains, that could be global to the entire cell or tissues, or local to individual proteins – and…of course, in ubiquitous coherent states (Del Giudice, Stefanini, Tedeschi, & Vitiello, 2011).

The new concept of ‘stored energy’ developed by (Ho M.-W. , 2013) is a good starting point, much better than the usual ‘free energy’. ‘Free energy’ cannot be defined *a priori*, much less it can be assigned to single molecules. Even changes in free energy cannot be defined unless we know how far the reaction is from equilibrium. ‘Stored energy’, originally defined by McClare with respect to a characteristic time interval, has been extended to a characteristic space-time (Ho M.-W. , 2013) (Morowitz, 1968). As such, stored energy is explicitly dependent on space-time differentiation, hence it is a precise concept, defined on the space-time domain of the processes involved. Stored energy has meaning with respect to single molecules as much as with respect to the whole organism. The organism can be considered, first and foremost, as an energy storage super-domain, and stored energy is coherent energy capable of doing work at the specific space-time domain in which it is stored.

However, it is important at this point to deepen one last aspect: how energy can be mobilised only when demanded, resonances of coherence being at work always.

2.4 Fractality and nested coherences: the keystone

It’s a well-known fact that nature loves fractals (Mandelbrot & Wheeler, 1983) and they are ubiquitous 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 (Voss, 1988)). Fractality in nature is not only meant geometrically, but, also dynamically and fractal dynamics also provided the proper theoretical tools to understand enzyme kinetics, mass

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[5] Actually we should give a clarification: as I said above the nested space-time levels pertain to several degrees of coherence. So, when we’re speaking of “thermalizing” energy at a given level it’s not properly said, because those excitations are made ordered (free) energy and not heat. But, as they are released out of the coherent domain of their corresponding space-time scale, they result as excitations spreadable over a manifold of states tending to distribute (like the single trajectories of the gas particles inside the piston, which on atomic scale constitute kinetic energies, but at macroscopic level they results as heat). So, if regarded from the larger scale, such an energy has so shorter times of equilibration that it is as if it were transferred at the equilibrium and as if it were a unique macro-state. Right as the ordered expansion-work of the piston with respect the entropic disordered heat of the colliding thermalized gas.

transport and thermodynamic flow-force relationships (as the Onsager's ones, seen above) in the cellular microenvironments (Welch GR., 2010).

The relationships between what have been discussed so far and fractals is promptly clarified by a series of recent works (Celeghini, Rasetti, & Vitiello, 1992) (Celeghini, De Martino, De Siena, Rasetti, & Vitiello, 1995), (Vitiello G. , 2007), 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. Quantum coherence thus appears to underlie the ubiquitous recurrence of fractals and self-similarity in Nature (Vitiello G. , 2009). In other words, self-similarity can be expressed in terms of a deformed coherent state and vice versa. This allows us to affirm 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, that is: they are characterized by macroscopic dynamic properties (growth or formation, morphogenesis, bioenergetics, organization, etc.) which are not understandable except in terms of an underlying (microscopic) quantum dynamics.

Aon and Cortassa (Aon & Cortassa, 1994) studied the fractal dimension in micrographs of cytoskeleton and emerged that it behaves as a *percolation cluster* (or a *random fractal*). A percolation cluster is the ensemble of holes or sites in lattice connected to a chosen centre to which a fluid is injected so that the fluid will percolate to those sites. The most remarkable feature of percolation processes is the existence of a *percolation threshold* below which the spreading process is confined to a finite region. The percolation probability, $P(p)$, is the probability that a fluid injected at a site, randomly chosen, will enter and wet infinitely many sites. Below the percolation threshold, the cluster behaves as a locally connected, while above it the connection extends indefinitely. Near the critical probability P_c, as the number of holes p is increased, the percolation process undergoes a transition from local to global connectedness.

Tang et al. (Tang, Liu, & B., 1994), using an optical microscope with video recording to track the movement of fluorescent particles in living cells, discovered three modes of movement: local mode, in which the particle is confined in a limited region of cytoplasm (radius 0.64 µm); extended mode in which the particle has an extended trajectory (radius 2.73 µm); and a mixed mode in which some parts of the trajectory are local while other parts are extended (average radius 2.28 µm). Twenty-five log-log plots, of the linear segment size (into which were subdivided the total track) versus the number of segments, showed straight lines with slopes (i.e.: its 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, may well be energy, travelling along molecular backbones and membranes in form of solitons, photons, polarons, phonons, spin waves, etc. (Fröhlich, 1983) (Del Giudice, Doglia, Milani, & Vitiello, 1985), (Brizhik, Musumeci, Scordino, Tedesco, & Triglia, 2003) (Brizhik L. , 2016). All of these are forms of ordered energy coming from the underlying nested coherent dynamics.

The above reports (Aon & Cortassa, 1994), (Tang, Liu, & B., 1994) confirm that, above a critical threshold, the cytoplasmic activities show a global *resonance behaviour*, where energy can "percolate" wherever the way is open, showing a global coherent resonant behaviour. But this process is tuned or switched on and off so that energy does not "leak", uncontrolledly. Let's see how water coherence and cycles are the key to understand this amazing "mechanism".

Now we know that 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 the key to understand how resonance can be tuned, yielding a mechanism which allows coupling and energy transfer from a level/compartment to another, and why fractality lays at the basis of mobilisation of energy (Ho M.-W. , 2013).

When a system shows some patterns (or dynamics, like cycles and frequencies) at different scale levels, it's interesting to consider which is the ratio among the levels within the involved scale window. If we consider the frequency, or the oscillation period (or the wavelength) of the cycles of coherent oscillations within a system, it is interesting to evaluate whether these ratios are rational (or even integer) or irrational. In the two cases we would have two different outcomes: resonance and phase coupling or closure and local autonomy. Secondly it is interesting to consider whether these two conditions (to open or close the energy transfer by resonance) are arbitrarily "switchable" from/to one another, as to estimate whether these different work regimes/layouts are easily undertaken by the (sub)system (Ho M.-W. , 2013).

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Panchelyuga and Panchelyuga (Panchelyuga & Panchelyuga, 2012) outlined an interesting aspect about the distributions of rational and irrational numbers showing that the latters are arbitrarily close to the formers and that the rational numbers distribute inhomogeneously along the $\mathbb{Q}$ set, and precisely in a fractal way (self-similarly in increasing the width of the considered intervals).

What is interesting is right the "numerical proximity" existing between rational and irrational numbers, that can express the easiness to pass from a condition of resonance (rational, or even integer, ratios among values of dynamical quantities of the system) to a condition of uncoupling between oscillators (irrational ratios among the values).

A condition of resonance occurs between a system named *q* and a another named *p*, for instance if the ratio, *r*, of their frequencies, is a rational number: $\omega_p / \omega_q = r \in \mathbb{Q}$; if $r \in \mathbb{N}$ we speak even of harmonics; if $r \in \mathbb{Q}^*$ (the irrational set), no resonance exists and the systems have non-commensurable frequencies, and the phase space is described by KAM toroids, or quasiperiodic orbits (Broer, 2003), (Arnold, 1963)).

Panchelyuga and Panchelyuga showed that rational numbers have dense neighbourhoods to irrational ones. This means that systems wherein coherence exists need very tiny self-tunings to switch from dynamical closure, to percolation (energy transfer by resonance coupling). Irrational and rational numbers distributions related to the same physical system are the "tuning ground" across which the latter can modulate its internal constraints in order to shift 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, at the smaller space-time scales, in living systems such changes can be extremely fast dealing with processes that pertains electron or ion oscillations, vibronic states of molecules, folding/unfolding of proteins, cyclic strains in enzymes, and so on (Ho M.-W. , 2013).

Now it's possible to account for the physical basis of the ability of tuning from non-resonant (irrational ratios among frequencies) to resonant (rational/integer ratios) and vice versa. It has to be kept in mind that this possibility is rooted right in the special features of the spectrum of the water molecule, which gives us one more reason to mean this "alchemical" substance as the *molecule of life*.

As we showed along the previous sections, 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^{-10} eV and can be selected through several ways which, as a matter of fact, require no energy expense (Del Giudice E. , 2007) (Bono, Del Giudice, Gamberale, & Henry, 2012). Indeed, the oscillation frequency could be easily changed by phase variations in time due to tiny electric currents among CDs (acting like Josephson junctions (Del Giudice, et al., 2005), (Smith, 2004)), 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 (Del Giudice, et al., 2005) can induce shifts in the proper frequencies, switching compartments / domains from irrational (closure) to resonant (open) mode and vice versa[6].

Many studies, we think, should be run to verify these theoretical proposals, but it's reasonable to conceive that such available "continuous bands" of possible states could be found in many more degrees of freedom on which coherent domains establish, and not only on the sp^3-5d oscillation, i.e. on: ions coherent domains, dipolar rotation of water molecules, for instance, and not only of water molecules (Yinnon & A., 2009); other possibility could be: coherent oscillations of ortho-para nuclear spin configurations in biological water (Sliter, Gish, & Vilesov, 2011), phonons bands, polaronic sates, spin density waves, etc.

The landscape that opens up is immense and new, because allows us to look at living matter as a set of "interwoven quantum-based devices" where several physical quantities (electric and magnetic fields, mechanical – sound – waves, density, pressure, frequency, temperature, electrical charges, masses, dipoles, spins, photons, phonons, etc.) work entangled together to express really a *symphonic* behaviour where everything depends on everything else, despite maintaining at an emergent level its own "dynamical identity" (the emergent *self*), closure and local autonomy. Right what any living system is in essence.

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[6] Of course, such strong dependences of the functioning of biological matter on so many tiny variations of fields and phase correlations are involved in the still complex ambit pertaining to the effects of extremely weak electromagnetic fields on living beings (De Ninno & Pregnolato, 2016).

However, such inquires, in order to reward us of fruitful results, should be run on the basis of the theoretical approach reviewed so far, out of a perturbative conception of ground states (Preparata G. , 1995), possible only by taking advantage of the powerful and consistent tools of quantum field theory, gauge field and symmetry breakings theories (Del Guidice & Vitiello, 2006), (Blasone, Jizba, & Vitiello, 2011).

Eventually some final considerations about why nature loves fractals so much can be consistently derived now. It's clear that the well-recognized astonishing thermodynamic ability of living systems to manage their own internal energy comes from their cycle-based functioning (Ho M.-W. , 2007) (Ho M.-W. , 2010). As it's known, if some chemists attempted to replicate the same chemical pathways which a single cell performs every second, for instance, they would fail dramatically (a lab as large as a nation would be needed) without being able to create cyclical pathways, i.e.: the reactions would not return to the starting point in the most of the cases (no autopoiesis), and the efficiency and the speed of such reaction performed in a laboratory would be hugely lower than *in vivo* (Milgrom, 2016), (Milgrom, 2018). The reason of this lays in the absence, out of living matter, of nested coherent hierarchies interwoven and tuneable. Super-coherence is the physical reason for the existence of cycles, coherent, ordered, rhythmed, coupled, oscillations at several, nested, space-time structures (Ho M.-W. , 2013).

The *living phase of matter*, a water-based coherent matrix inhabited by a minority of other molecular species[7], 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 each other, to each of those 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).

The locked-ness among levels means that it's impossible to change the parameters at one level without affecting all the others (Ho M.-W. , 2010), like in *matryoshkas*. These levels are all phase-coupled (like a music band playing on the same *tempo*) but are not frequency multiples one another by default, otherwise no compartmentation or stored energy would be possible, because of resonance which would transfer energy all around. That's why fractal structures emerge, where the nested-ness is joined to non-multiples ratios and non-resonance unless it is decided. This guarantees stability and autonomy. But this condition has to be modulated easily in order to allow energy mobilization, and fractality allows right to enter resonance conditions through tiny tunings of work-frequencies, so that parts of the system can couple together and exchange energy matter and electric charges.

As also Mae-Wan Ho and al. hypothesized (Ho, el Naschie, & Vitiello, 2015), (Ho M.-W. , 2013), now it emerges so clear why in the living realm fractal structures are so implemented: they have both a dynamical origin (coming from the nested-ness of coherences and cycles) and a functional one (being the fractal, irrational, ratios among self-similar structures, at the several space-time levels, those ones which guarantee a stable autonomy, despite the openness of the system).

Thus, Nature (physics) 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 (Panchelyuga & Panchelyuga, 2012) (Ho, el Naschie, & Vitiello, 2015). This is why the activities can remain distinct. However, the fractals are also close to harmonics that do resonate, so phase coupling and energy transfer through resonance is readily achieved by shifting from fractals to harmonics. In nature, the golden ratio is implied in an overall scale range, revealing an underlying fractal (holographic) organisation of physics in general, and not only of biological realm (Haramein & Rauscher, 2008). Such a shift from fractals (irrational) to rational (or even to integer, harmonics) ratios may coincide with the threshold for *percolation* in which local connects with global.

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[7] See, for instance, the values reported in (Neidhardt, 1996) of molar fraction and percentage of molecular and ionic species constituting a bacterium of *E. Coli*, to have an idea of how much is the order of magnitude of the differences in quantities between water and the other species.

3. Discussion: physics of perception, semantics and adaptation

Now we have the theoretical tools to derive some physically based hypotheses about *semantics*, a delicate point among all those astounding features shown by the living systems, impossible to be reduced within a mainstream (molecular) approach in biology and physics. Firstly I recall here the main issues.

As we hinted in the introduction, the ability to *perceive* is necessarily rooted in the ability of maintaining the components – which the system itself is made of – in a special physical state which allows them to "communicate", to "know", or, better, to *share* their state. In fact, if each component were not "informed" about the state of all the others, we would not be allowed to talk about "responses" (appropriately told to be typical of living systems), but at most only about "reactions" (in a strict chemical or physical meaning). It would be possible to predetermine the chemical outputs or to write the Hamiltonian of the system and to establish an, at least surjective, correspondence between inputs and outputs.

That's not the case and not only because we cannot know all the equations of motion of the components. Such an impossibility is also due to the fact that each component "spotted out"(to which assign physical quantities like energy, momentum, mass, etc.), constitutes an arbitrary partition of the system, which in this case could not even be "a good approximation" since, when many nested coherences are at work, no numerable oscillator is describable *per se*, and by doing this, all the information about its phase would be inexorably lost. This is due to the uncertainty relationship holding between the quantum operators the two complementary observables, phase and number (Blasone, Jizba, & Vitiello, 2011) (Preparata G. , 1995) (Umezawa, 1993).

Secondly, such an impossibility to reduce a response dynamics down to a predictable reaction, is due also to the fact that the resulting eigenstates, which occur along the history of the coupling between living system and environment, unfold by exploring (non-locally) through quantum fluctuations a huge manifold of equally possible "trajectories" in the phase space, which cannot be foreseeable *a priori*, even by knowing ideally the initial conditions with infinite detail (Umezawa, 1993) (Del Guidice & Vitiello, 2006).

We know now that this particular condition, which implies openness, phase-locking, high sensitivity to little stimuli, realization of outcoming states in dependence on history and on context, is right *super-coherence*, where a holonomic multiplexed and tuneable phase-locking holds over a vast manifold of degrees of freedom (ranging, at least, from electron oscillations up to circadian, endocrine and life cycles, passing through meso scales of space and time).

Organisms in this enlarged view, do really appear as self-emergent *choirs* or *symphonies* without a director. Mae-Wan Ho, indeed, suitably referred to this condition as to a *quantum jazz* (Ho M.-W. , 2010), (Ho M.-W. , 2006) by meaning that all the components enjoy local autonomy and play their "melodical tracks" (at their own proper frequencies and performing their cycles, i.e.: improvisation), despite the several voicings are all "phased" at a common background *tempo*, a common rhythmic embedding (which yields the emergence of a wholeness of the harmony, i.e.: the emergence of a – perceptive – *identity*).

This is what allows a *self* to emerge: an irreducible dialectics between (i) the inescapable basic *openness* and *coupling* to the environment (where an unceasing exchange of matter and energy would make it impossible to define with arbitrary precision what belongs to the system and what does not) and (ii) an astonishing dynamical *stability*, where (just emergent) "autonomy" , "identity" and "freedom" appear. A living being, indeed, is stable in the sense that it maintains its own structure-function (even across generations) despite it is essentially an *open process* through which quanta of matter and anergy (and phase correlations) are unceasingly exchanged with the environment (which is right its thermodynamic, dissipative, time-reversed *double* (Vitiello G. , 2001)).

3.1 The difference between inanimate and living matter

It could be useful to make a short reflection about which differences could be seized between inanimate and living matter, the latter being associated to super-coherence.

Inanimate matter is typical to exhibit "action/reaction" relations only with respect to inputs. If the inanimate system is fully incoherent (like a gas, for instance) only inputs carrying some forces or energy produce effects (for as we know or measure). If the system enjoys some degrees of coherence, we know that the Bohm-Aharonov effect also allows for phase correlations to produce effects (not limited to speed of light and, somehow non-local, carrying no energy) (Aharonov & Bohm, 1959).

Anyway, this kind of effect, if regarding an inanimate system, is still on an action/reaction level (despite no force or energy transfers are involved (Aharonov & Bohm, 1959), (Batelaan, 2009)), because, for simple functions of the phase, the outcome is more or less unique: the equations below indeed show how the phase of a quantum system is related to the potentials V (scalar) and $\boldsymbol{A}$ (vector) and not necessarily by fields $\boldsymbol{E}$, $\boldsymbol{B}$, that can even be null, (h is the Planck constant, c, the speed of light in vacuum, e, the electric charge of the electron Φ_B is the magnetic flux, φ the phase and $\Delta\varphi$ its variation and t the time, we're considering MKS in S.I. units):

$$V = \left(-\frac{\boldsymbol{\hbar}}{\boldsymbol{e}}\right)\frac{\boldsymbol{\partial\varphi}}{\boldsymbol{\partial t}} \quad [Volt] \quad ; \quad \boldsymbol{A} = \left(\frac{\boldsymbol{\hbar}}{\boldsymbol{e}}\right)\boldsymbol{\nabla\varphi} \quad \left[Volt\cdot\frac{sec}{m}\right] \qquad \text{(Eq. 3.1.1 a, b)}$$

$$\boldsymbol{E} = -\frac{\boldsymbol{\partial A}}{\boldsymbol{\partial t}} - \boldsymbol{\nabla}V\left[\frac{Volt}{m}\right] \quad ; \quad \boldsymbol{B} = \boldsymbol{\nabla}\times\boldsymbol{A} \quad \left[Volt\cdot\frac{sec}{m^2}\right] \qquad \text{(Eq. 3.1.2 a, b)}$$

$$\Delta\varphi = -\frac{e}{\hbar}Vt \quad \text{or} \quad \Delta\varphi = \frac{e}{\hbar}\nabla\cdot(\nabla\times A) = \frac{e}{\hbar}\Phi_B \qquad \text{(Eq. 3.1.3 a, b)}$$

In the presented approach, this effect is relevant only when the phase of oscillation is well defined, thus only in coherent systems, and it is crucial in keeping correlations within living (super-coherent) system. However, it is interesting to consider again that the complementarity relationship holding between the operators phase (φ) and number (N), $[\varphi, N] = -i$, (with i the imaginary number: $\sqrt{-1}$), which rules their uncertainties is not limited to the quantum, Planck, scale: $\Delta N\cdot\Delta\varphi \geq ½$, in natural units (where $h/2\pi = c = 1$), $\Delta N\cdot\Delta\varphi \geq 2\pi$ (in MKS units) (Preparata G. , 1995). (Judge, 1964).

This aspect is pretty interesting since would suggest some physical dynamics underlying phase correlations among coherent systems also at macroscopic levels. This would be also supported by the fact that the ground level of oscillators in a coherent system is lower than the one when they are isolated, and coherence is much more stable (and favourable) as much as the phase is better defined. To sharply define the quantity "phase" means to increase the uncertainty of the number of (fundamental, quantum) oscillators participating to an in-tune oscillation, and the paramount way to achieve this is to increase right the number of oscillators sharing such a phase (Preparata G. , 2002) (Del Giudice, Stefanini, Tedeschi, & Vitiello, 2011). This is a spontaneous physical dynamics since it strengthens the thermodynamical stability of coherence by increasing the number of oscillators (and CDs) sharing a common phase, since the maximisation of phase sharpness deepens the energy gap, the ground (vacuum) level, strengthening the coherent state (Del Giudice, et al., 2005). In living systems, increasing the overall number of phase-locked oscillators stabilizes *homeostasis* (meant as their ability to cope with stimuli which drive them out of their balance). Such a balance, made of a dynamical self-maintenance through energy/matter cycles and feedbacks, has been defined *homeorhesis* by Conrad H. Waddington (Waddington, 1968-1972).

Though it could appear a daring "epistemic jump", bringing to a scale shift of super-coherence too, this concept had been conceived (Brizhik, Del Giudice, Jørgensen, Marchettini, & Tiezzi, 2009) as a physical relationship (beyond the ones implied by exchanges of matter / energy and mutual dependences as food-chains, symbiosis, and trophic networks (Barnes, 2018), (Saint-Béat, et al., 2015)) which keeps (non-locally) correlated living systems among each other, in a further choir-like step of phase-sharing. Namely it has been provided a physical tool to figure out one more aspect of what we call *ecosystems*: space-time regions wherein the living beings share phase-locking on some degrees of freedom[8]. If this conceptualization could be possibly proved, the

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[8] It's important here to make a specification: the kind of phase-locking implied in electrodynamic super-coherence is a quantum correlation through the electromagnetic potentials, which does not imply any energy or force transfer (Del Giudice, Stefanini, Tedeschi, & Vitiello, 2011) (Brizhik, Del Giudice, Jørgensen, Marchettini, & Tiezzi, 2009). Thus, such a correlation pertains to those (coherent) objects which show quantum oscillations: the more or less fundamental "bricks" – as electric charges, ions, molecules, colloidal aggregates, membranes, proteins and microscopic structures – producing coupled oscillations cycles in the nested structures, which altogether constitute the (super-coherent) living system as a whole (regardless it is a single cell or a pluricellular organism). Such correlations occur on given degrees of freedom and not on others, guaranteeing connectedness and local autonomy at the same time. Some examples can be provided by synchronizations occurring among individuals like: brain waves in humans (Pérez, Carreiras, & Duñabeitia, 2017), light pulsations of fireflies (Buck & Buck, 1978), or collective motion in flocks (Evans & Patterson, 1971), (as in swarms and fish schools), and of physiology cycles (like the corals' spawning (Chelliah A, 2015), just to make an example). Such phase correlations, I suggest, could be reasonably deemed responsible both for geographical orienting ability and sensing (Becker, 1985), or even foreseeing, cosmological, telluric, climatic events, or in "special sensing" of pets towards their owners (Sheldrake, 2011)

This kind of phase-locking are not always accountable for by classical physics (or by chemistry) which can conceive and describe synchronizations only if some transfers of energy or matter (chemical signals) are at work. A typical example of such a classical synchronization is the one occurring among equal metronomes, placed on a common floating basement, being subjected to the momentum exchange among each other through the basement.

As well explained by Umezawa and Vitiello (Umezawa & Vitiello, Quantum Mechanics, 1985), biological systems work classically (since macroscopic), but thanks to, and right because of, their quantum basis. Thus, beyond the classical pathways, non-local phase-locking at macroscopic scales in biological realm would be possible via quantum dynamics, that is: involving some degrees of freedom physical grounding in coherence and dissipation of ecosystems (Del Giudice, Pulselli, & Tiezzi, 2009) would be a deep breakthrough in understanding how *Life* works. And I'll discuss in the following which scenarios such a framework opens up about evolution in biology too.

As we introduced in the first section, *perception* is something much more "integrated" and complex than "detection" and pertains to the "stimulus/response" level where univocal outcomes are not guaranteed and the relation between input and output is strongly tailored by *initial conditions*, opening a huge plethora of possible successive configurations in the phase space.

Nonetheless, this requisite is necessary but not sufficient to yield a system able to "perceive". Indeed, also in chaotic or complex inanimate systems, such a univocal relation between action and reaction (input and output) isn't feasible since a high sensitivity to initial conditions holds (Baranger, 2000). However in these cases we are still speaking of non-living systems, or systems where no coherence is present (like in turbulence, traffic on roads, or social flows through urban architectures (Iliopoulos, 2015)).

In any case, we must remember that, both in living and inanimate matter, we always deal with deterministic systems (though not arbitrarily predictable), that is: systems where the fundamental laws (at which mathematical univocity holds) are ever at work and no ontological discontinuities are postulated among fundamental and emergent levels, as well as between matter/energy and something misleadingly called "information", thought of as "a thing" (a "magic fluid", an unspecified field) to be superposed to the former. Again, this would be a cartesian, inconsistent, dichotomic, perspective (Vitiello G. , 2001), (Renati, 2015).

In fact, also *living matter* is subjected to deterministic laws, because made, emerged out, of energy and matter and their dynamical constraints; thus, where new categories and laws appear, of course, they must be still in full agreement with the fundamental ones. Let's think, for instance, of the refractive index of a transparent crystal: it is a property (with corresponding laws) which cannot be retraced down to the interaction of single atoms with light, but which have to be consistent with those at that elementary level. A complex system is not arbitrarily pre-determinable because there is not a one-to-one ore even one-to-few relationship between an input and the possible output states of it.

However, this is not enough to speak properly of a "responsive system", even less of "perception". Why? Because it is needed that the eigenstate of the system is "known" by the whole, that is: a state that all components share losing their individuality. This is the case when just *coherence* is present, where the state of the system is given by a common eigenstate of phase over all its constituents. For instance, as we hinted in section 2.2, CDs of water molecules are dynamical aggregates where all the molecules (on that degree of freedom) share the same wave-function and any input from outside (if small enough in order not to break coherence) does not produce as many states as the molecules involved in the interaction, rather a global change of the state of the whole CD (Del Giudice, Spinetti, & Tedeschi, 2012). The molecules have no individuality anymore for the laws of QFT (i.e.: well-definiteness of the phase implies non-enumerability of the quantum state, i.e.: no more possibility to participate to such a state as individual components) (Preparata G. , 1995).

For this reason and for the intrinsic openness, we may say that a CD does not only *react* to physical stimuli but *responds* too. Of course such a "reply" is still very simple, but *in nuce* it's the same kind as the dynamics showed at much more manifold and complex levels, where coherences interweave one another and (at need) phase-lock together (Ho M.-W. , 2013), (Ho M.-W. , 2007) yielding what in living matter, as we told above, has been called *super-coherence* by Del Giudice et al. (Del Giudice, Stefanini, Tedeschi, & Vitiello, 2011), (Tedeschi, 2010), (Voeikov & Del Giudice, 2009).

Thus, simple coherence is not enough to yield "perception" and *living* phase of matter. We need a multiplexed manifold of coherences, where the several degrees of freedom are more or less directly locked to one another: this is the condition which allows for a *self* to emerge and for speaking of a system as a *one*, as a biological *identity*. In synthesis, in such a theoretical perspective, what allows a system to perceive, and to be regarded as "living", lays in the peculiar configurations of energy and matter, implied by super-coherence (a fractal, multi-layered choir of coherences) so that the following requisites would be contemporary satisfied:

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of oscillation pertaining to given coherent cycles in the hierarchy constituting the organisms. I am proposing that this would be a consistent physical basis to figure out ecodynamics and evolutionary pathways as globally organised, non-random, *holomovements* of the whole *Life* (see section 3.6). Of course, to such dynamics, the one associated to random stimuli occurring in the environment, has to be summed. To these latters, the "web of life", in the word by F. Capra, displays non-predetermined coping strategies, time by time and in dependence of their amplitude (ruling whether coherence on a given level can be maintained or not).

(i) high sensitivity to initial conditions (expressed also by Weber & Fĕchner's law (Chisolm, 1911) (Cope, 1976) (Nutter & Esker, 2006) (Tosi & Del Giudice, 2013)),

(ii) openness and dissipativity: time-depending coupling with the environment (Vitiello G. , 2001),

(iii) far from TD equilibrium states, shared on the whole (Voeikov & Del Giudice, 2009), where inputs do not produce manifold states assigned to single components (or to sub-groups of them). This last point tells about the existence of long-lasting excited states which do not tend to thermalize, since the living state is essentially rooted in maintaining dynamically a balance where a minimisation of entropy be anyway guaranteed.

3.2 Time-dependent coherent states: the base of perception and adaptation

Now, the possibility can be suggested for a more in-depth physical analysis regarding how and why coherent states are the key to let *qualities*, teleology, and adaptation to emerge in perceptive relationships.

Thinking of the examples given in the introduction (regarding the antelope and the woman in their respective meaning-endowed situations, stressful situations in the case), we know very well how, just for making an easy example, the adrenaline hypersecretion by the adrenal glands is a consequence of "something" perceived as "danger", "shock", or any circumstance (especially if unforeseen) that is intended in a *way* as to imply (if considered possible) urgent 'flight or fight' (in mammals, we know well that this is one of his roles).

Nevertheless, going beyond neurotransmitters, such a mechanism is not reserved only to complex pluricellular organisms, but is prerogative of every living being – regardless of its simplicity or archaicity – which is, by default, able to elaborate the (inner and outer) environment conditions and to act in compliance and usefulness for its own survival, i.e.: it's able to *perceive*.

Let's think again of the simple amoeba (mentioned above) that "knows how to choose" whether to get closer to a nutrient or move away from a toxin, even in complete absence of neuronal equipment or of any properly "cognitive" processing. "To know the environment" means to modify the inner state and structure of the living, otherwise it is not a real (physical) interaction, but just a virtual idea, a narration. The amoeba modifies its own interior – where precise chemical reactions also appear, at least for the mere movement of the cytoskeleton resulting into the protrusion of filopodia – as a function of the exterior to act "behaviours" useful for the preservation of itself (or of its own species or, even, of a bigger context[9]). The changes manifested in the interior, physically coupled to the state of the whole <living system (amoeba) + environment (its «double»)> (Vitiello G. , 2001), are aimed to, and suitable for, certain purposes. They make (biological) sense!

This is precisely the (quite earth-shaking) point: categories such as (biological) "*purpose*" and "*sense*" seem to play a key-role in understanding the reasons for physiological layouts (and more generally for living "functioning"); and such categories, more than to be reducible to which list of reactions/components is implemented in the system, are rather related to "*what these reactions are useful for*". Those reactions are carried out with (and are able to satisfy) a precise *purpose* (i.e.: activating a physiology suitable for ...). They are triggered by very specific *meanings* (physically based) for survival, homeostasis, functioning, etc.

It's here that we can proceed into the physical definition of *meaning* and to understand what *to perceive* (and *to respond*) really denotes, distinguishing it from just detecting or measuring. In order to develop structures in consequence of functions, we said before, it's necessary that the system "knows" its own new state caused by a given stimulus so to implement processes aimed to the maintenance of its thermodynamic and electrodynamic suitable conditions for being alive (its homeostasis, its coherence, its well-defined phase).

To do that it's necessary that the outcoming state is able to fulfil contemporaneously three assignments, which are right those that can be satisfied if such a system is *super-coherent*. Because of coherence and all that it implies about the responsive dynamics we discussed above, provided the stimuli carry energies inputs smaller than the overall *energy gap*, each physical interaction between the living (super-coherent) system and whatever kind of stimuli (included inner modifications of the state of the former and including absence of inputs too, since also the steadiness of the conditions constitutes a stimulus in fact) entails the following outcomes:

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[9] This pertains to the self-adjustments which generally occur in nature, balancing the demography of species (through specific behaviours) or of cells within a tissue (through apoptosis). All these events, aimed to maintain biological balances, cannot be comprehended as something initiated by the single cells, by the single individual or by the single species; on the contrary they become consistent and justifiable without *ad hoc* hypotheses if we consider, through the QED view, ecosystems as space-time regions where phase correlations are at work which holonomically link all the coherent (living) systems as a whole, up to a planetary scale, the biosphere, as well explained in ref. (Brizhik, Del Giudice, Jørgensen, Marchettini, & Tiezzi, 2009).

- The living system is provided with (i) "*knowledge*/information" of the environment (including itself).
- In order to do that, (ii) a *modification of the state* of the living system itself has to occur (otherwise the knowledge would be just virtual and would hold only for kind of "brain representations", if any brain is present).
- The update to a new state in consequence of the interaction / coupling implies (iii) *to realize the most suitable possible state* (in dependence on the configurations reached till that moment) for the maintenance of the coherence. Why is this the case? Because the living system is physically coupled to the environment and to itself through the constraints regarding thermodynamics and electrodynamics (and also mechanics, kinematics, etc…), i.e.: the outcoming state is necessarily still coherent and "shaped" on the (new, or identical) occurring boundary conditions. Such a state consists in the adjustment of all the physical quantities apt to minimize the energy ground level, maximize phase sharpness and this super-coherent state is the premise for any other following state. This is how adaptation occurs.

On the long-term, this process creates structures/functions already able to perform fruitful tasks by default, this is right *adaptation* (of the structures owing to the functions required). And the satisfaction of the three assignments above explains why it is deeply and necessarily related to perception, in a physical sense. This opens up the way to understand better evolutionary pathways.

So, what does it mean "to perceive" and what does it mean that a given stimulus or "situation" (condition) has a *meaning* for the living system (regarding its possibility to perform its biological typicality)? It means that, in dependence on whether the given configuration of the environment (internal and external) maintains (or even increases) or threatens (or even destroys) its super-coherence, there are two groups of possibilities:

- either the creation (or the continuation) of a physical state which corresponds to the same, suitable, conditions for life or their improvement;
- or, oppositely – if the configuration of environment threatens its survival (or the expression of some default functions), that is, if it depletes the coherence of the living system – the new updated global state of the system is right the one to which processes apt to restore the optimal coherence (homeostasis) correspond, when feasible.

Otherwise, if coherence is destroyed, the system is dead.

By "state" we mean the coherent quantum state, virtually a global wavefunction of the whole organism (the state made of that manifold of nested cycles and respective coherences we analysed so far). And "weakening and reinforcement" of super-coherence could be regarded respectively as the diminishing and the increasing of the depth of the "global" *energy gap* given by the "sum" of the energy gaps related to all the sub-coherences of each degree of freedom on which cycles are performed.

The sentence assessing that the state of the living system derived from the interaction with the environment (form the perceptive event) is right the one (or one of the possible many) "suitable one for restoring coherence" looks like quite arbitrary. Yet, it could be not, and the reasons are at least two:

(i) the deepening of energy gap is a thermodynamic principle driven by the tendency (for an open system) to minimize the ground state (vacuum) on a lower and lower vacuum level. associated to such a stabilization, as we saw, there is also the further defining the phase of oscillation (this minimization occurs despite the coherent state is also "made of" a content of free/stored energy in excess with respect to incoherent state) (Blasone, Jizba, & Vitiello, 2011) (Preparata G. , QED Coherence in Matter, 1995);

(ii) such a "compliance", between what physical laws would prescribe for the updating of the state at a new step and the "suitability" of such outcomes for the maintenance of life, is reasonably the result of a history along ages which, for sure, could count many "unlucky (or better ineffective)" cases among which some good chances had occurred and, therefore, gave to some subjects the possibility to fix such subjective stories about the time-dependent series of all the assumed states (and consequent structures) in what we call "physical body" (as a matter of fact: an open process, not an object).

And after a history long enough, time by time, the n^{th} configuration, for a while, is the one perfectly adapted to the environment (till that moment, in those conditions), able to cope with all the already known tolerable stimuli (opportunities and threats). However, the fact that a maximization of coherence is always at works implies that further adaptation and adequation of the eigenstates is spontaneously (thermodynamically and electrodynamically) performed by each organism. This is what, on an emergent level, is called phylogenesis: the history of the dialectics between changes in the environment and adaptations and differentiations of the most suitable configurations in living systems.

In synthesis: within the living phase of matter, each interaction must actually be regarded as a *perceptive* act, where an emergent *self* is *experiencing* its physical coupling with whatever occurs inside and outside itself, because all its constituents (quanta of matter and fields) share some interdependent phase-locked states (losing their own individuality as “parts”). The super-coherent status, entails: (**i**) *openness* to the environment (a continuous flow of matter, energy, and physical states which succeed one another in a non-predetermined but synchronically deterministic time-dependent sequence-history), (**ii**) a scale of nested inter-locked tuneable coherences, and (**iii**) the conservation of a far-from-thermodynamical equilibrium state. These three terms do constitute the necessary and sufficient conditions to engender the living state of matter.

Such assignments, as far as we know, are fulfilled by the aqueous matrix constituting all living systems, because of the amazing array of chemical-physical properties and the spectrum of states of the water molecules (Tedeschi, 2010).

3.3 Emergence of meaning as a quality-based process

So, despite *meaning* is fundamentally related to constraints that refer to laws of physics, it is a subjective category and not an invariant. This is due to (*i*) the asymmetry of dissipation with respect to time arrows, (*ii*) the non-invariance of the physical configuration in dependence on the observation (interaction, perception) perspective, (iii) the unrepeatability of an ever flowing reality, where – for instance – the third time a fact occurs, is not equal to the second one, just because the second time had already happened and a history configures along the arrow of time (this concerns the problem raised about the fact that in living dynamics it’s not enough to describe the evolution through thermodynamic state functions (Del Giudice, Pulselli, & Tiezzi, 2009)).

It appears, hence, that *meaning* is an objectively, physically rooted, *subjective* category, which, despite uncomfortable and unmeasurable, science (biology and medicine above all) should deal with in order to envisage an organic and fruitful *reducti-holistic* view of Life.

Practically, *perception*, through “meaning” (i.e.: what physically the input implies for the living system state), produces a new environment-coupled state in the organism, that corresponds to a precise oscillatory configuration of itself, to which precise chemical pathways are associated, i.e.: a given physiology is the material outcome of the *semantic* (physical) *coupling* between the living subject and all that it interacts with (in and outside).

In mammals, such a configuration that, moment by moment, updates, could be denoted as the neurovegetative *visceral map* (Damasio, 1994) and pertains to the configurations of manifold body parameters as: nerve tone in parasympathetic and sympathetic sub-systems, levels of activity in organs, blood pressure, heartbeat frequency, hearth rhythm patterns, temperature, tone of smooth muscles and of blood vessels, skin conductance, peripheral blood perfusion, hormone and neuropeptides concentration in bloods and tissues and many other aspects (among which many of them are still unknown like, for instance, some important bio-electromagnetic variables as biophotons emission and their frequency distributions, amplitude and districts in the body where a given emission occurs). The *visceral map* is related to the *quality* of such a perceptive coupling, since – like we discussed – is right the *quality* of the interaction, intended as its subjective *meaning*, that matters.

The *visceral map*, in turn, is something *sensed*, *felt*, by the living subject itself: in fact it is the way it “knows” about the lived situation, about the stimulus (and about itself) as we described above: only by the changes occurred inside, thus *felt*, the organisms become aware of whatever status of the context. The *visceral map* is *felt* because it is right the inner state that is engendered by the same perceptive act (a physical change), and it becomes, in turn, *object* of the (self)perception and turns into what could be called *feeling*, and eventually, *emotion*.

Of course, each feeling – as a chemical-physical state – corresponds to a given visceral map (Damasio, 1994) and the link to coherence is that: to a given oscillatory configuration of the global interwoven nested super-coherences, a given performed biochemistry and a corresponding physiology (on macroscale) are related. This is true for all that we described in section 2.2: the work-frequencies determine the molecular encounters through resonant selection. Different proper frequencies, different pathways, different physiologies.

Here, we become able to give account for the nowadays well established relationship between “stress” and “disease” (Maté, 2003) and that had been discovered by researchers as Hans Selye (1936), Walter B. Mason

(1971), John W. Cannon (1929), (1932) (American physiologists), Henri Laborit (French biologist, ethologist and philosopher) (1959), (Kunz, 2014). And we can do this in a much deeper way, now also by reframing the point of observation. That is: the physiological expressions also in disease cannot be looked at as "failures" or "bad functioning" anymore, rather as (part of) processes developed by the living through a "biological sense". And such a "sense" in this context is not a 'mental idea' or just a linguistic category. It is meant in a physically grounded manner, that is: the kind of effects that a situation/stimulus implies for the coherence of the organism.

The living system being super-coherent cannot engender "random", diffusion-ruled events and what we mean as "mistakes" are due to our limited vison / knowledge of the picture. Like when we are looking at an anthill and think that ants' "traffic", is something "chaotic". Actually, in such a frenzy there is not a bare shadow of randomness. The "chaos" is in "the lack of information", in our incomplete knowledge of what and how each ant is perceiving (and aiming to).

Each time, to a given stimuli, some adequate adaptively developed responses (physical and chemical processes) are implied. And these responses are adequate because engendered within coherence, which "tends" to self-maintain (being thermodynamically at a lower ground state, despite far from equilibrium and rich in stored energy). Thus such responses are endowed with a (biological, physical) *sense* (i.e.: what they imply, and what they are useful for, their *purpose*, that is, the final state reachable by acting them).

Purpose, *sense* and *meaning* have very little to do with "microscopic" in the common use of the term because they cannot be found by digging down in molecules and genes. Rather, the formers reside in their relationships with the world. Surprisingly, hazardously, it may be that molecules and genes behave right *in consequence* of the formers (as also epigenetics is beginning to show (Darnaudéry & Maccari, 2008), (Avramova, 2015)). The presented discussion, reveals a scientific view able, though heuristically, to *reduce* such analogical and qualitative categories to "hard" physical basis, but at the same time it's also able, by a *holistic* attitude, to look at the (living) system taking account of its *quality-based features*, so crucial to understand its state. That's why we call this approach "*reducti-holism*".

Perception, thus, consist of integrated dynamics based on response, pertaining to the qualitative aspects (the *qualia*, would be named in neurosciences) of the interaction itself with respect to the perceiver. Thus, *quanta* describe the action/reaction level, whilst, let's say, *qualia* speak of the stimulus/response one. In this sense we mean *qualia* as analogical *qualities*, the "way the perceiver feels something", also in elementary unicellular organisms therefore not circumscribing the meaning only to neuro-scientific field, nor to brain-endowed systems (Lowe, 1996). For example, think of the difference between a condition implying *safety* and a condition implying *threat*, as we exemplified in the introduction, (the *qualia* are the effect to the perceiver of such situations/stimuli, their *qualitative* feature emerging in the interaction with the context). Here is the basis of *semantic* aspects of physical relationships and the emergence of the category of *meaning*.

3.4 In living systems information is configuration

Some due reflections pertain to possible advancements in conceiving what "information" (including a comment about *qualia*), "complexity" really mean in the special case of living matter, as well as about the dynamics of "evolution". Let's start with the first one in this section.

In our usual conceptual attitude, *semantics* is related to the topic of "information" for sure, and this is somehow correct and constitutes a not obvious enrichment to the inquiry approach, since too often science is habited to speak of "information" through the ideas developed in information technology (IT), telecommunications (TC) and TD, without considering *semantics*, as pointed out by Logan (Logan, 2012).

The problem to me, indeed, resides right in what still today is meant by "information" in mainstream science and in common sense. In those restricted fields of application as IT, TC, TD, the idea provided by C. Shannon of "information" as something related to the quantity of bits needed to code / decode in a stripe, that is related to its entropy (to how much the source for instance is aleatory) works well (Shannon, 1948). However, as Shannon himself alerted, this idea of information should not be considered in general. And it should not be tight to the idea of a "signal" transferred from somewhere to somewhere else and it should be untied by the idea of a discrete sequence of "units" (bits, q-bits, digits) (Renati, 2015).

As Lawrence Kubie well highlighted, in science «*we are constantly in danger of oversimplifying the problem so as to scale it down for mathematical treatment*» (MacKay Conferences) (quoted in (McLuhan, 1964)).

Our reduction of the problem to a sort of "algebraic manageability" is of course of great utility, especially in science of complexity in order to model systems and to estimate some outcomes in simulations. However when this approach is applied to "information", it implies a collapse of the latter to a mere "quantity" (concerning for instance how many bits, or how much energy, entropy, etc. are engendered in a process). This makes us to disregard, especially in living dynamics, the *quality*, that is: how relationships among the represented, descriptively distinguished parts are configured. Dealing with *qualities* is really uncomfortable, it's true, because there's nothing to grasp by itself and to be inserted into equations or summed up to other "pieces" in order to provide objective data, numbers.

However we must be aware that, even admitting that this could be always done, such a practice would imply a huge lost. It's like to know that a geometric polygon has 3 sides and to extract the number "3" as the datum which represents the system. By doing so, we cannot speak of the *shape* of the triangle: the *shape* expresses which is the *configuration* of space and the *qualitative* relationship (geometrically speaking in this case) between an 'inside' and an 'outside', while the *number*, conversely, does not speak of this *quality*. The shape is right a *configuration*. And, in an organism, what is the precious "information content", if not right the configuration, the space-time organization?

As we said above, unlike for IT or TC (Shannon, 1948), where it defines how entropic, disordered, the transmission between source and receiver is, in living systems, "information", is rather opposite to entropy, being the dynamic ordering of the activities. It is firstly a *configuration*, and it's an essentially *analogical* variable (Renati, 2015, p. 41-45) pertaining firstly to the *mobilisation* of energy *with specificity*, efficiency, coordination and in a time-dependent (cyclical) sequence of exchanges, in precise sites and amounts. And such a mobilisation has to be performed in perfect coupling with the (unpredictable) fluctuations of the environment. All of this *magic* (actually just physics of coherence!) is built on the organism's nested spacetime structure, *compartmentation* and *closure*, that, in turn, is a result of nested degrees of coherence (Ho M.-W. , 2012), (Ho M.-W. , 2013), (Del Giudice, Pulselli, & Tiezzi, 2009), (Brizhik, Del Giudice, Jørgensen, Marchettini, & Tiezzi, 2009).

Even more, in living realm also the fictitious division between "software" and "hardware" (of data and substrate, of message and medium) fails dramatically. As pointed out by McLuhan in organisms «the *medium* **is** the *message*» (McLuhan, 1964): living information, is just a configuration and consists of the web of functional, topological and energetic *relationships*. This relationship-ness is actually their configured materiality: DNA, RNA, enzymes, coherent water, proteins, and so on are in fact the *medium* and the *content*, the *message*, and the *messenger*. The medium is literally the content (the message) and the content of the message is unique for that medium (Renati, 2015).

3.4.1 A short comment about qualia

It's not surprising that the qualitative feature of semantics in living dynamics, and its physical expression through the process of perception as based on QED super-coherence, is quite connected to neuroscience themes, like the problem of *qualia* and of "cognition".

By meaning *qualia* as "analogical qualities" (the way the perceiver feels) (Lowe, 1996), and not limiting them to "brain-cognition", since involved also in elementary unicellular organisms, we could say that: the category of *quanta* may describes the action/reaction level, whilst that of *qualia* speaks of the stimulus/response level. Just to make a trivial example: the felt difference between a condition implying safety (perceived that way) and a condition implying threat, we may say, pertains to the qualia of the configuration, made however of the quanta and quantum states involved in the physical dynamics.

Quanta, in principle, are numerable, tell about "how many", "how much", "*qualia*" is not the plural name of "one *qualium*". To think such a way means not to understand what "quality" means and to fall back in the reductive concept of "information" deprived of configuration-relationship. Quality is not ascribed to quantity; it is right in *qualities* that the emergence of (non-invariant and context/subject dependent) *meaning* occurs.

What has been discussed about super-coherence, like the *conditio sine qua* no living state is feasible, leads us to bring an objection to the principle of "organizational invariance" by David Chalmers according to which, at the same level of organization (and complexity), of "informative contents" and properties, independently on the nature of basic constituents (whether they are neurons or transistors or quantum-dots, etc...),. the existence of *qualia* (thought of as the requisite for the emergence of consciousness) would be possible in any kind of system, provided it is sufficiently complex/organized (Chalmers, 1995).

Despite, for what I said above, I think it makes no sense to think of *qualia* as "particles of consciousness" – because they should pertain to the relationship, and to the qualitative effects (configuration) on the perceiver with respect to the coupled context – Chalmers' principle, even if could be conceptually correct, to me suffers from two flaws:

- firstly, it neglects that any "organizational level", or "complexity", as well as any "information content", are uniquely epistemological concepts, are our own ideas depending of our arbitrarily assumed isomorphism between reality and its description (in fact disputable (Renati, 2015) (Renati, 2016)). The limits within which we consider organization are just a "scale window" and furthermore in such conception of "information", as criticized above, we are not concerning many other kinds of correlations and sub-structures that escape, not only our tools to observe the systems, but also our categories according to which something is considered as a correlation, or a functional bond, and something else is not (but which actually could be);
- secondly, it implicitly postulates that the kind of physical state experienced by the components makes no difference: the correlation among transistors are local, diachronic and causal because they are not super-coherent among each other; conversely, the neurons (like every other kind of component in living matter) enjoy common phases, entanglements, and constitute a true "coherent field" where "information", better to say *configuration*, is not "transmitted" or "received", but rather it emerges from the collectiveness of such field-waves (Freeman, 2005) (Freeman, 2009) (Freeman & Vitiello, 2008) (Vitiello G. , 1995) (Vitiello G. , 2009). This is an irreducibly analogical condition, it allows *synchronicity* (instead of only diachronicity), *teleology* together with causality. This is possible only when (super)coherence gives a holonomic feature to the (entangled) system.

Eventually, a comment pertaining also to artificial intelligence (AI): suitably designed quantum dots, as possible basic components for an artificial organism (expressing some "conscious" dynamics), could ideally even satisfy some "boundary conditions" to trigger super-coherence[10] as to some kind of "living phase" may appear.

However, super-coherence implies nested oscillations and cycles of energy / matter charge and discharge, in short: it implies thermodynamic openness (since the number of quanta must not be fixed, otherwise the phase of oscillation cannot be sharp). This means that there cannot be clear-cut boundaries separating the artificially implemented system and its environment, and that a recirculation of matter/energy flows is at work: no possibility of real confinement, no 'isolability' and no control of any potential artificially created "organism". This is firmly inadvisable.

As a final consideration we could lay down a question: why to pursue such a road, whose outcomes would imply further departure away from our Natural sacred womb, only because we technically are able to do it? Why not to decide that science and technology must be a *tool* (to be used within a sensitivity in the name of respect and humbleness in regard of Nature and of Life in general, not only human!) and not a goal?

I lively hope that scientists and humans all over the world could wake up soon in this sense.

3.5 Complexity in living systems

Complex system physics it's a rapidly expanding branch of science which deals also with the developing of mathematical (and informatic) tools suitable to simulate (and predict) the behaviour of various analytically irreducible systems, sensitive to initial conditions, ranging from social networks, to financial economy, transports, epidemiology, seismology, metabolomics, genetics, ecodynamics, etc. (Kwapień & Drożdż, 2012), (Zurek, 1989), (Barabási, 2016) (Kauffman, 1993). Such studies began to raise among scientists a higher awareness in regard of the fact that determinism and predictability go hand in hand only in the minority of the cases in the real world. This fact is helping into increase also the sensitivity towards *qualitative* aspects of physical dynamics which, for sure, play a key role in living systems.

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[10] And not only a simple coherence, otherwise even a crystal, a magnet, or a superconductor would be "alive" and able to perceive and adapt.

To us, one more interesting aspect to underline is the fact that complexity is commonly told to be found *at the edge of chaos* (Lewin, 1999), (Waldrop, 2019) denoting that the "ordering bounds" coupling the components of a system cannot be neither to weak, so to give purely chaotic behaviours (like in a gas), nor too tight, so to give a rigid (inert) order (like a crystal). Actually, when coherence is in force, as we described well in the previous sections, the order is mainly a *time-order* which transduces into ordering of motions of the participating objects, when suitable boundary conditions are satisfied. This *motional* order is that of condensed phases like liquids (including some special phases of plasmas and glasses), liquid crystals, superfluids, phonons and electrons in superconductors, for instance; and above all for that special kind of "liquid crystals" in the case of living matter (Ho, et al., 2006), (Ho, et al., 1996), (Ling G. N., 2003).

However, in the special sub-set of complex systems represented by the living ones, based on nested and accurately tuned entangled coherences, the situation could be looked at differently from non-coherent or inanimate complex systems. Within living beings, indeed, the most sophisticated complexity is reached thanks to two conditions: *i*) increasing the number of components, the number of links and the number of their typologies (i.e.: the variety of stimuli to which the system reacts/responds, by which it is affectable), ii) keeping precisely tuned and arranged all the relationships among the components, or sub-portions of the system itself, and the ratios among the observables (as frequencies) at several space-time scales.

The first point deals with the fact that evolution, from unicellular systems, pointed towards pluricellular (larger) ones along phylogenesis; and this point is rooted in the physical uncertainty/complementary relationship between phase and number operators we saw above: the more the number is large and the more its uncertainty is big, thus yielding the phase's one further minimized. By this way, the coherence is strengthened because the coherent ground level (*vacuum*) of the oscillators is lowered.

The second point deals with the fact that the maximisation of complexity occurs when organization (time-ordering of oscillations and spatial specificity where energy exchanges occur) is at the top, and we could say it means a minimization of chaos and entropy. Nonetheless this maximised organisational dynamical "order" occurs without falling into a rigid static "crystallinity" (that could appear as "too much" order and fixity, scarifying complexity).

As Schrödinger already reported, in living dynamics we have to do with *order from order*, and it is an order with no repetition (Schröedinger, 1944), if such order relied on randomness it would be a disaster. Indeed, as we tried to resume in section 2.2, biological ordering of structures and cycles is obtained by coupling the components among one another through many coherences, many degrees of freedom on which in-phase oscillations can be established (overlapping and nesting one another), i.e.: this "alchemy" is obtained right by interweaving several degrees of inner order, orderly related to one another.

Thus, in the special case of living systems, regarded as super-coherent open processes through the framework of QFT and symmetry-breakings theories, the *maximisation of complexity* means right *maximisation of space-time organization* (what has been called *motional order*), that is: an unceasing refinement of tuning of work frequencies (and sharing of the phase), so that all the performed cycles perfectly work alongside one another.

In living systems, the idea of complexity *at the edge of chaos* should be refined, specifying the dialectics occurring between the intrinsic features of the living state of matter and the plethora of random stimuli coming from the environment. Provided their "amplitude" do not overcome some energy gaps, decohering the systems, this mixture of order (the dynamical organization of the biological systems) and chaos (the environmental stimuli to be coped with by keeping inner organization) produce the maximization of complexity and drive also evolutionary paths through a synergy between the "chaotic" stimulation of physical reality and the "ordered" replies of living matter.

Of course the concept of "order" could be perspective dependent, let's make an example: it's well known that a good, physiological, and efficient brain functioning has to be neither too 'chaotic', nor to schematically 'ordered' in its pattern of neuronal activity (which, are just distributed linearly in log-log plots of frequency vs power, or in log-log plots of size of the neuronal districts involved in oscillations vs number of oscillations bursts (Freeman & Vitiello, 2008) (Freeman & Vitiello, 2006), (Vitiello G. , 2009) (Vitiello G. , 2004)). However, this does not mean that it's partially "chaotic", rather it means that a healthy functioning needs some ranges and ratios between different scales of collective oscillations, and each undertaken regime, in a healthy brain is perfectly "wanted", and is not result of randomness. The randomness lays in the plethora of stimuli to be faced during the brain homeorhesis, and the kind of reply is never random, but based on a deep and widespread organisation. It couldn't be otherwise, since the brain is an aqueous super coherent water-based structure where coherent components (neurons and glia) constitute a whole dynamic *matter field* (Vitiello G. , 2009).

This fact is also confirmed by how low is the thermodynamic expense compared to its huge amount of "operations": the human brain, about 1.2 L in volume, has an estimated memory of 3.5 × 10^{15} bytes, operates at a speed of 2.2 petaflops (10^{15} operations per second), and consumes 20 W in power; in comparison, the world's fastest supercomputer in June 2011, the Fujitsu's K computer having the size of a small warehouse, had a memory of 30 × 10^{15} bytes[11], operating at a speed of 8.2 petaflops, and consuming 12.6 MW (Fischetti, 2011). I repeat, this is not difficult to accept by taking into account the fact that in living matter there is no portion, actively participating to the physiology of the organism, which is not (in manifold-way) coherent (Ho M.-W. , 2010) (Ho M.-W. , 2012) If it weren't so, the choir of nested cycles and the hugely many biochemical pathways would be immediately messed-up (Ho M.-W. , 2013).

Thus, about order, as said above, it holds likewise for an anthill: to us it appears to have a certain degree of chaoticity, actually each ant knows what to do and follows olfactory (as well as possibly electromagnetic) trails and perform precise tasks in each moment and there is no randomness in their behaviour if not about the fact that they respond (organisationally) to random environmental stimuli. This lets to emerge the peculiar kind of complexity in the special sub-set of living systems: the inherent dynamical multi-hierarchical order of their constitution coupled, through stimulus-reply dynamics, to the chaos of a context teeming of inputs. A little different way to conceive the *edge* of chaos. In a further study we could face the problem of the definition of "order" or "chaos" as conditions intrinsically dependent to the observation perspective and categories.

So, through a deep inclusion of coherence as the basic building-block of the living state of matter, a meaningful enrichment in the definition, and premises, of *complexity* belonging to the living dynamics should be accounted for: in living realm, unlike many-body incoherent systems (financial, social ones too), complexity is could be deemed "at the edge of chaos", but in a different sense: i.e. by referring to the fact that living system are dynamically (motional-ly) ordered and organized system whose trajectories in the phase space are engendered by they organised response to (also) random, chaotic, stimuli. Indeed their inner constitution is engendered through higher and higher finely tuned (super-coherence based) relationships, which allow *local autonomy* and *global connection*. That's why such kind of increasing ordering/organisation does not imply fixity, nor prevents dynamicity and evolution (both essential for the living state), quite the opposite.

3.6 Evolutionary paths and ecodynamics

From all said so far, we can well envisage that inner coherent ground of living dynamics addresses us to a more spread conception of *evolution* and *ecosystems* too. The Darwinian idea of "selection" among a variety of mutations, randomly produced, cannot be regarded as the main driving force of evolution anymore. Some kind of "selection", in the true meaning of the term, could occur, at most, in a circumscribed variety of cases (typically in regard of dramatic changes such as cataclysms, and the effects of technology, whose "amplitude" and speeds at which they take place don't match with space-time scales of biological dynamics).

Firstly, such concept of "selection", to me, has been always suffering from appearing quite unrealistic. Speaking for instance of diploid organisms, as mammals, it's highly improbable that two (or more) individuals in a species have, at the same time, the same "random" mutation (due to chaotic fluctuations, noise, stochastic processes in gene transcriptions, etc.) so that they could mate and that their own offspring could find other equally mutated partners to mate with and, again, always accidentally, this could occur each time, for each species!) for sufficient many generations and that a new hereditary character establish.

Secondly, this scenario is conceived in the usual "diffusive paradigm" in biochemistry and molecular biology describing molecular events in living matter on a stochastic (short-range) basis which, as we demonstrated along all this study, suffers from many inconsistencies not compatible with living dynamics. These deemed "random fluctuations" should occur inside a matter made of a super-coherent water-based matrix, wherein actually no random/uncorrelated events can happen; if it were so, it would be the ceasing of the living

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[11] Of course, such an evaluation of the "memory" is still reductively made within a conceptual framework which postulates a (at least) functional isomorphism between the discrete, digital data storable in (non-living) hardware and the analogical, relational (continuous, un-detachable from one another) configurations of living matter.

process because of the decoupling of components off their cycles (Del Giudice, et al., 2005), (Del Giudice, Spinetti, & Tedeschi, 2012), (Ho M.-W. , 2013).

All of those "improbable" happenings (that reveal even useful for adaptation!), actually, have been occurring for a long time (billions of years). And if we think to the physiological responses of the examples mentioned above (antelope, woman, amoeba), the reasons for these mutations cannot lay in randomness, but in the physically rooted dynamics of stimulus/response discussed above, and we could spot out two contributions which are at work.

The first "driving force" in adaptation/evolution can be thought of as local, pertaining to the thermodynamic and perceptive history experienced by the living being. We highlighted before how the condition of super-coherence implies that at each interaction with the environment the system updates itself, physically, to a state which fulfils three assignments: (*i*) the "knowledge" of the context (safe/threatful) which occurs through how (*ii*) the inner state changed, which implies (*iii*) a new layout suitable to maintain coherence in those conditions (if these ones do not destroy it). We remember that "interaction with the environment" also includes the *perception* of inner states and the consequent (more or less) efficient performing (within the environment) of some *functions* in relation to which to develop / to change the suitable *structures*.

Of course evolution is not predictable and shows a random feature too because of the intrinsic randomness of the stimuli which come from the environment (climatic, geologic, cosmologic events together with anthropisation and technological impacts included): another picture showing life dynamics at the edge of chaos, meant in a more encompassing sense.

Now, considering that this adaptations (i.e.: this updates to "special" states of the super-coherent layout of the system) cost energy, and considering the fact that coherent states succeed one another in a time dependent law of evolution, where the whole configuration <living + environment> affects which is the outcoming global state, it's easy to conceive that, along the history, the living system approaches more and more a configuration able by default to cope with the environment and even to be specifically apt for it. So, adaptation is not a "random fluctuation" that sometimes works and sometime doesn't. Conversely, it is an *oriented*, in progress (and possibly causing improvement) process, well-rooted into the coupling between living being and environment in the non-random (coherence based) stimulus/response dynamics. In presence of dramatic modifications of the environment, the adaptive change along the evolutionary history can be enough to survive and improve, or not (and this could mean even the extinction for a species).

The second "leading force" playing a role in evolution, as well shown by Brizhik et al. (Brizhik, Del Giudice, Jørgensen, Marchettini, & Tiezzi, 2009) could be considered as non-local, rooted in the Bohm-Aharonov effect seen above and entailing, ideally, to the vast set of species that live in an ecosystem and the huge variety of interrelations through their vector-potential, carrying no energy but just the phase (Aharonov & Bohm, 1959). A vector-potential carrying a well-defined phase can be produced by every coherent ensemble of quanta, but can be detected only by coherent systems, therefore this kind of *holo-correlations* (wide as the wavelength of the coupled electromagnetic modes, up to thousands of km) creates an evolutive network among living beings and their environment.

As discussed in section 3.1, phase correlations and order extend (by dissipating entropy) to larger and larger scales (among coherent systems only) owing to the *uncertainty relationship* holding in QFT between phase and number operators exists. The lower bound of the uncertainty of the number is given by the very number of subsystems: $\Delta N \leq N_{tot}$. Thus, by increasing N_{tot}, and "opening" the system through resonance with other living beings makes $\Delta\varphi$ to become very small (squeezed coherent states (Celeghini, De Martino, De Siena, Rasetti, & Vitiello, 1995)). This witnesses also how opening to the environment, getting in resonance with other living beings, is at the base of empathy and experiences like love and beauty (Del Giudice & Tedeschi, Science and Aesthetics, 2011).

I suggest the idea according to which evolution is the *non-random* result of the (adaptive) physical long-range couplings between living (sub)systems and their (partially random and partially coherent) context. Evolutionary paths can be now regarded of as much more encompassing and *holographical* dynamics, deeply rooted into coherence-based *adaptation* and therefore into *perception*, as we described it previously in a QED framework. It is no more "one species" to evolve, but the whole web of an ecosystem (at least), or of the entire biosphere (Brizhik, Del Giudice, Jørgensen, Marchettini, & Tiezzi, 2009).

4. Conclusions: outlining some main remarks

By considering the water-based electrodynamic coherence as the paramount foundation of living matter, along this work I discussed the following topics:

- among the several striking features of living systems (as high thermodynamic yields, biocommunication, efficiency and precision of the undertaken biochemical pathways, morphogenesis, autopoiesis, etc.) the most puzzling and hard to reduce, down to fundamental physical dynamics, is the faculty to engender *meanings* associated to the *experienced* situations, stimuli, boundary conditions and their ability to *respond* by displaying non-random *configurations*, not univocally pre-determinable though endowed of some (biological) *sense* for keeping homeostasis or survival; this ability to *respond* and to be sensitive to “what a state implies” is what I refer to as *semantics* and is ascribed to the dynamics of *perception*;
- this faculty doesn’t concern cognition, it holds transversally for an amoeba, a tree, a human being;
- it has been considered that the *causes* (in strict sense) for the living functioning cannot be found at the molecular scale *tout court*; the usual approach in molecular biology and biochemistry usefully and fruitfully describes the dynamics of cellular metabolism, or protein coding through genes, for instance; but this does not tell anything about *why* a given physiology (or genetics expression, or cellular activity in general) is undertaken among many possible ones, and does not even tell a lot about how such responses are possible by considering the molecular encounters as mediated by (diffusion based) stochastic dynamics; such a diffusive/molecular approach leaves unanswered also the other features mentioned above (morphogenesis, biocommunication, energetics) and supports a vision of adaptation and evolution conceived as ‘statistic trajectories’ based on “random mutations”;
- to me, that’s not the case, since such an “ergodicity” in evolution would not match the evident non-randomness of physiological and biochemical responses to whatever is experienced, that is: it is really hard to justify that a common “functional ground” could give ordered outputs (as physiology, sensing, behaviours) in some cases and random outputs in other ones (evolutionary paths), especially because the latters always point towards a functional/structural improvement between living system and environment; when, at which level, by which criteria (if any, thus: why?), and how would a switch be turned from “random” to “ordered” (and sensate)?
- semantics expressed in living systems regards the ability to be “susceptible” to what experienced situations *mean* for their own state, this implies the emergence of *qualitative* features entering the dynamics of response and perception; *qualities* cannot be accounted for by simple (surjective) action/reaction links and cannot be differentiated if any randomness is into play;
- moreover this qualitative feature of the configurations (qualia) is not reducible to quantities (quanta per se) but needs a relational approach to the definition of information, which in living systems cannot be considered the same as conceived in informatics, telecommunication (bits or q-bits) or thermodynamic (related to the entropic content); living “information” is rather *configuration* since essentially rooted into relationships; relationships are not invariants and depends on the *context*, the *history* and on the specific *perceiver*; this is what allows *meanings* to emerge;
- such a qualitative relationship with the coupled environment implies underlying forms of order which allow configurations to be differentiated, since some degrees of symmetry are broken;
- within this reflections, I claim that the idea of evolution and adaptation based on “selection among a manifold of random variants” is not realistic and quite a “clutching at straws”; the point is to find a qualitative (physics based) convincing portrait of living matter which, by using the less number of *ad hoc* assumptions, could account for the largest amount of phenomenologies displayed by living systems keeping well clear that they’re open thermodynamic structures, far-from equilibrium and entails minimum amounts of internal entropy;
- to search for a possible answer to which physical dynamics could underly the emergence of meaning and semantics I addressed the focus on what physically means to respond, and which are the differences between response and reaction;
- *response* has been identified as the first necessary, but not sufficient, condition in order to engender the living state; the maintenance of the system on *stable excited states*, far from the thermodynamic equilibrium, and its *open-ness* are the other two ones;

- however a further condition is needed: the possibility of the system to act as a *whole*, where any stimulus and response (determining a given eigenstate of the system) implies the sharing of such a state over all the components; such a sharing of the state means that all the components "know" the state of the other ones, so that the response constitutes an intrinsically *holonomic* process;
- such an assignment is achievable only through a state that in physics is called *coherence*; when the conditions above are satisfied, a system is able to *perceive*, that means essentially to change its inner state, in consequence of the inputs, on a manifold of possible outcomes which are elected according to a time-dependent array of configurations coupled to the environment (the thermodynamic *double* of the open living system); to undertake such responses as a *whole*, phase correlations must be at work;
- reviewing the valuable researches pursued in the framework of QED, the living phase of matter is outlined as a special case of condensed matter which, in such theoretical framework and within symmetry-breaking theories, is the result of various kinds of coherence established on collective oscillations on given degrees of freedom (yielding several kinds of order); such a speciality is ascribed to the super-coherent state, that is a condition wherein many kind of coherences are at work, creating a nested hierarchy where all degrees of oscillation depend on one another, implying that all the work frequencies create a finely tuneable *polyphonic choir* where a phase-locking (resonances) among them is established when "needed";
- such a sophisticated layout is feasible just because of the special features of water molecules (about their spectrum of the electronic states) and of their collective dynamics when condensed; in particular, the presence in water coherence domains of a dense band of collective states for the quasi-free electrons between the excited level (chosen for the coherence in the liquid phase) and the ionization threshold and its neighbourhood to the former, are the features allowing for such a tuneability of oscillation frequencies;
- this fact is crucial for the emergence of living dynamics since it provides the coherent domains – constituting the water-based matrix in living matter – the ability of engender a vast manifold of easily available states in dependence on the external inputs and allows the domains to establish wider nested levels of coherence (where domains of domains of domains… oscillate in phase) provided that other molecular species could participate to the coherent dynamics thanks to the matching of their own proper modes – spectral lines – with some of the frequencies of the water-based "background choir";
- the above said lets us to understand how it is legitimate and reasonable (based on physics) to speak of (biological) *sense* by which the responses in living matter are undertaken, and explains, at least qualitatively, where *teleology* comes from and how it is rooted into thermodynamic history through *perception*: the update of coherent states along time produces adequations to the environment driven by the tendency to stabilize coherence both via extending the number of oscillators (as to sharpen the phase) and via updating the default state in order to cope better and better with stimuli that could push quanta out of coherence,
- from such a "forging" during time of super-coherent eigenstates, along which arrays of states continue to produce new premises for the successive ones, the structural "design" is derived too;
- this is true because living matter – made of more than 90% of super-coherent water in molar fraction – is moulded through the field gradients and the interference patterns produced by the standing waves of the self-trapped coherent fields inside variously shaped and sized coherent domains: this means that the change of states in super-coherence (water disposes of "infinitely" many levels) results into a change of oscillation frequencies, thus a resonance-driven change both in molecular encounters and of spatial distributions of matter occurs (due to rearrangements of interference patterns); this kind of relationships between wave-patterns and space distribution of matter at macroscopic scale is also known as *cymatics* (made via sound waves) or as dielectrophoretic effect (via time-varying electromagnetic fields in which different kind of particles are soaked, and gather / pile up in space regions also in dependence on their dielectric constant, mass/volume ratio and shape); such dynamics are involved in morphogenesis too;
- all of this manifests like the presence of *cycles* (both in thermodynamical and electrodynamical sense), associated to the several degrees of coherence, spanning from timescales of the order of electron oscillations (10^{-13} sec) and spatial scales (wavelengths) of the order of nanometres, up to timescales of

seconds, minutes, days, moon-periods, seasons, and the whole life cycle (and larger and larger spatial scales, up to the whole planet);

- nested coherent oscillations create nested cycles to which high-order energy storage is feasible as well as the compartmentation of space (in accordance to the wavelengths of coherent modes); such intimate and full-scaled compartmentation (made of membranes, molecular backbones, tubules, vesicles, niches, microsites, pockets, folds, etc.) guarantees the minimization of entropy despite allows energy transfers from local to global and vice versa via two thermodynamic regimes: fast (via resonance) and slow (via equilibration "thermal energies");
- "thermalizing" energies are those released by (however little) dissipation as manifold of microstates from a "small" level to a "large" one (in dependence on their scale ratio); the "disordered" microstates can be exploited by the latter in form of work because (and if) its time scale is significantly slower so that such manifold of microstates (whose time of equilibration are much shorter than the relaxation time at the larger/slower level) an be exploited as ordered energy (like a piston of an engine, producing work out of the random, thermal, molecular kinetic energies of the expanding gases); in this way, in fact, no disordering is produced and no entropy is kept within the oscillation cycles;
- resonance among cycles occurs when their frequency ratios are rational (or even integer: harmonics), and this condition is feasible thanks to the fine tuneability of super-coherence in the water-based matrix of living matter; naturally such modulation is function of the relationship with the environment and of the history;
- of course, in default conditions, in order to avoid unregulated energy transfers, it's necessary that frequency ratios assume irrational values, so that phase locking does not occur; mathematical studies showed how distribution of irrational numbers within a number set shows density maxima arbitrarily close to those of the distribution of rational ones (and this proximity increases at lower values of the number axis); this fact would allow to super-coherence to easily pass from in-resonance to off-resonance layouts via negligible energy expenses and via phase correlations too; by this way cycles guarantee at the same time local *autonomy* and global *stability*;
- this hypothesis is supported by studies showing how irrational ratios exist for some systems (as for brains frequencies, heart-rate frequencies, geometrical proportions, etc.) and other studies showed how cytoskeleton can be regarded as a *percolation fractal* where its non-integer dimension represents the slope of the line obtained by plotting the number of segments versus their length; the water-based super-coherent system is able to modulate the frequencies of oscillations in order to release energy (i.e.: excitations of various forms, electric charges as well) via resonance from sites to others and in precise moments, also in dependence of the coupling with the environment;

All of this shows that:

- an extremely high level of dynamical order is present within living matter, and that its "information content" is ascribed to high sophistication in choosing moments, rhythms, sites, quantity and quality of energy / matter mobilization across the compartmented structures; this kind of dynamical order is right what allows biological system to work and implies the dissolution of any dualism between structure and function, medium and message, psyche and soma, "energy-matter" and "information";
- such an astonishing degree of ordering supports the idea that all the inside-coming manifestations of living systems (from movements of cytoskeleton in single-celled organisms, up to an adrenal incretion in a mammal, up to behaviours, as well as memory and consciousness, adaptation and evolution) find their aetiology on a common super-organised dynamics, where qualities do matter;
- moreover, a possibly more refined definition of "complexity" about super-coherent (living) systems is required with respect to how is conceived for non-coherent ones: complexity showed in living realm is based on a super-organisation dynamically ordered of living matter interfaced and ordinately responding to partially random environmental stimuli, in this sense we could speak of "edge of chaos"; the inner multi layered order does not imply any stiffness or "motional hindrance" of the system, but rather the opposite due to the fact that such a kind of order is motional;
- in qualitative features of whatever kind of interaction/situation (*meaning*) and in such a relational configuration (*semantics*) we can find the *causal dynamics* of physiology, biochemistry, sensing,

behaviours, diseases, homeostasis, etc. much more consistently than by digging down into molecular scales: what occurs at the molecular scale is the *way* how such a function is unfolded and performed, not the reason;

- this view of living matter suggests us that all of its expressions are non-random and acted for some purposes aimed to preserve (and possibly improve) homeostasis (i.e.: super-coherence): this explains how biological *sense* and *meaning* are something real and coupled to physics, despite they are neither *invariants*, nor measurable quantities (because they are *qualities*!);
- in the portrayed view, adaptation and evolution are rooted on the same ground as perception, response, semantics: they cannot be driven randomly tout court, rather they emerge as an organized response to partially random inputs, and another key contribution could be given by the choral holomovement of the ecosystems meant as regions of space and time wherein phase correlations among living systems weave the web of life, which evolves like a *whole* super-domain of coherence (called *Gaia* by James Lovelock);
- this insight invites all of us (biologists, physicists, biochemists, geneticists, physicians, biotechnologists) to acknowledge an epistemological dignity to (analogical) subjective "observables" like meaning, sense, scope, experience. This would allow to understand many more things of *Life* and *Nature* as well as a unification of sciences and human knowledge in general;
- instead of wondering to ourselves "which are the *mistakes* within this or that cell, or tissue, making it to behave weirdly…?", we could question "which could be the biological *sense* (for itself or for the guesting organism) according to which this or that cell, or tissue, behaves differently?"; a little change of perspective, a huge enrichment of scenarios.

By considering this landscape as a good framework, which needs to be confirmed by further experimental studies and theoretical analysis, all the above said, could be useful for:

- improving our understandings in biology and its foundations in quantum fields dynamics, complex systems, and symmetry-breakings;
- widening the observation range in living systems, conceiving each one as a *web of relationships* with the environment and its own context, where *semantics* and *experience* (and thus feelings and emotions) plays a crucial role as well as like "hard" variables (chemical composition, frequencies and amplitudes of electromagnetic fields, etc.); this could offer more powerful tools in medicine and in understanding better the physical foundations of the well-established (but not fully understood) stress-disease relationship, and of epigenetics too;
- proving that more systemic approaches as quantum field and symmetry-breakings theories as well as science of complexity are extraordinarily powerful tools to describe nature.

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