Towards a Model of Life and Cognition

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1 Introduction

This essay is an attempt to answer the question: What should be the ontological foundation/s of the world that makes living and cognitive beings possible? For natural scientists this question can be translated to: What are the basic assumptions needed to build a science of life and cognition? It is possible to deal with the questions pertaining to life and cognition independently, but the point of addressing them together is due to an increasing awareness among scholars that they share a similar if not an identical foundation. Since I consider this connection between life and cognition a great insight, I would like to pursue further to explore the deeper interdependence in this essay. Most of the essay is a description of a hypothetical but a logically possible world with a defined ontological base, followed by indicating how a model based on the alternative foundations can indeed explain the actual world.

What is wrong with the foundations of the current apparently successful science? Biology rests today on quite a few not so well connected foundations: molecular biology based on the genetic dogma; evolutionary biology based on the Darwinian theory of evolution; ecology based on systems view; developmental biology by morphogenetic models; connectionist models for neurophysiology and cognitive biology; pervasive teleonomic explanations for the goal-directed behavior across the discipline; etc. Is this a problem or a virtue? It is possible to think that a complex domain like biology does need different approaches rather than a universal monotonic model. May be it is in the essence of biology that it escapes such a fit. But, is the non-living world so simple that a single theoretical framework could provide a comprehensive description? That there exists a problem in our current understanding is very eloquently put by Stuart Kauffman:

> Our fundamental theories in physics, and just one level up, biology, remain ununited. Einstein's austere general relativity, our theory of space, time and geometry on the macroscale, floats untethered to quantum mechanics, our theory of the microscale, seventy-five years after quantum mechanics emerged in Schrödinger's equation form for wave mechanics. Theoretically apart, general relativity and quantum mechanics are both verified to eleven decimal

places by appropriate tests. But it remains true that general relativity and quantum mechanics remain fitfully fit, fitfuly-un-united. And Darwin's view of persistent coevolution remains by and large unconnected with our fundamental physics, even though the evolution feature biosphere is manifestly a physical process in the universe. Physicists cannot escape this problem by saying, "Oh, that is biology."[13, p. 245]

The attempt to look for a foundation for biology may be confused with an attempt to reduce biology to physics. Reductionism is a belief that several domains can rest on a single foundation. If this foundation is that of the current physics, then reductionism amounts to reducing other domains of science to physics. The term 'reduction' implies that the foundation of physics is simpler than other domains of science: the underlying reality is simpler than the observed phenomena.

What if we explore for a foundation for a richer domain like biology, instead of an impoverished layer of reality like physics, and then *assimilate* the simpler domains into it? This move continues to be foundationist, but differs from reductionist strategy. Let us call this *assimilationism*. This is distinct from the two popular positions, reductionism and emergentism (holism), but is a reconciliation of both positions by appropriately identifying their domains. What this implies is to construct a foundation in the first place to explain biological and cognitive agents, and then see if simpler domains like physics and chemistry could be assimilated into it, possibly by systematically limiting certain selected parameters to generate simpler systems, and study the emergent properties of more complex systems that emerge due to interactions between them. Let the building blocks at the very core be complex enough!

The models employed by the traditional physical sciences are not rich enough to capture biological (and some of the non-biological) systems. These traditional theories depend on the assumption that the observed phenomena are *apparently* complex, while the underlying *reality* is simple. Instead of treating simple idealizations as an epistemological or methodological requirement for unravelling the secrets of the world, most began believing that the world is really simple, and began abusing our perceptions as illusory, and therefore needed explanations. This was more or less the spirit of the rise of mechanization of the world picture after the success of classical physics. While this strategy worked seemingly well for physical and chemical domains, its extension to complex systems (biological and social domains) was strained and not successful.

On the other hand the approach taken by the currently emerging theorists of complex sciences is for *emergentism* or *holism*. According to emergentism, new properties that were not seen in the parts of a system *emerge* only when the system as a whole begins to constrain, and exhibit *downward causation*.[1] General systems thoery[32] and cybernetics[2] explicitly suggest in their formulations that some of the properties of the system are caused by the parts,

[1]The term 'downward causation' was introduced by Campbell[5] to suggest the effects of a system that emerge due to the limits imposed by the whole on the parts.

and some other properties by the whole on the parts[11]. Thus, there exists a reasonable degree of realization of the need to reconcile the reductionist and holist approaches for understanding the structure and dynamics of complexity.

In what sense does my proposal differ from these attempts. Currently, the situation admits several partitions resulting in domains that do not share any commensurable property across the domains. For example, though we admit that complexity does increase during the course of evolution, we do not know precisely in what degree and in what terms. This makes the very idea of complexity undefinable. I think that complexity can be defined in measurable terms.[2] I think this cannot be achieved without a general and scientific theory of interactions. Thermodynamics provides such a theory partially, for it accounts for one kind of interactions, namely, IP interactions (see §6). Quantum physics provides for another kind of the interactions, namely, IT interactions (see §7) explaining the mechanisms at the atomic and subatomic level. The missing part of the general theory of interactions, dialogical invertibility (see §10), is one of the key proposals of this essay.

The strategy adopted here is to assume that (1) the underlying foundational elements are sufficiently, though *minimally* complex, (2) proposing a model of complexity as a fuction of the kind of interactions embodied by the system, (3) proposing a model of life and cognition as an embodiment of weaker (neither IT nor IP) interactions, and (4) discuss the implications of the model to understand the genesis, structure, dynamics and evolution of complex systems.

This is done without giving up any of the scientific ethos. What is scientific is still not a resolved problem. But, for the purposes of this essay, a scientific theory is a body of any systematic and falsifiable claims about the world we live in, formulated by using explicitly and operationally defined concepts. So, this exercise is just one among the various theoretical models attempting to arrive at a *different* scientific understanding.

The difference consists in a change not in the epistemic virtues of science, but in the prevailing questionable ontology assumed by the modern science. Possibility of multiple ontologies need not give rise to multiple epistemologies. Much of the criticism of modern science in the recent times, according to my understanding, is based on the incorrect perception that multiple ontologies corresponding to the multiple competing scientific theories need multiple epistemologies. This is not necessary. This issue deserves a separate essay, so I will not discuss any further on the connections between ontology and epistemology here, but the following section provides an indication of how multiple ontologies with same epistemic foundation is possible.

[2]Bedau believes that this is possible and provided degree of supple adaptation as one such criteria[4].

2 The actual world is a subset of what is logically possible.

Contrast this statement with: "The world is everything that is the case."[36] Readers familiar with philosophy literature will immediately realize that this was the opening sentence of Ludwig Wittgenstein's famous book, *Tractatus Logico Philosophicus*, written in the early years of the last century. I transformed the sentence to point out that logically possible space is wider than what is actually possible.[3] The model that we are building defines and generates a logically possible space, which we shall call *the possible world*. Everything that this model could generate may not be *true* of the world that we live in, which we shall call *the actual world*. But, if it can be shown that this actual world is indeed a subset of the constructed possible world, then it follows that the model is possibly true of this world.

This clarification is essential since the models that we come across in science do not correspond *only* to the physical systems of the actual world. They are also about the logically possible systems the model could generate. Our language is capable of generating a lot more "facts" than what are actually facts. We call these *fictitious* things respectfully, *theoretical*.

The theoretical scientific models may not actually refer to the directly observable phenomena out there. Science postulates processes and entities not directly accessible to observation in order to account for the phenomena that are directly observable. It is one of the essential features of scientific theory that it should have a capacity to deal with *possible states of affairs*. I therefore think that though science begins the 'journey' in search of principles accounting for problematic observable phenomena, it–in the process–constructs or creates certain structures which we normally call theories, that could account for not merely the observed phenomena, but also observable (not yet observed) phenomena and unobservable (in principle) 'phenomena' as well. Thus apart from what is actual, it could generate and account for "possible states of affairs". Here lies the *constructive* capacity of scientific activity.[4] In this sense what I am presenting here may be regarded as a theoretical scientific model.

Having clarified that the model being built is a theoretical construction, which is capable of generating the possible states of affairs, and a sub-set of possible states are the actual states of affairs, I begin the exposition of the model.

[3] During the course of this essay I will continue to transform a few more of the *Tractatus* like sentences into my own. This is not to criticize or ridicule Wittgenstein's point of view, because our objectives are not identical. But to serve the purpose of contrasting my world view with that of an atomist's.

[4] This view is generally called in philosophy of science as 'semantic view'. Bas van Frassen's articulation of this view is the most popular.[30]. More details on the constructive nature of scientific knowledge, and a possible method of construction are discussed in [18].

3 The two dogmas of science

In this section, as a prelude, I will identify two most important assumptions (when unquestioned may become dogmas) that are currently held by scientists. These assumptions according to my understanding are coming in the way of a science of complex systems to emerge. The assumptions are as follows: (1) living systems are thermodynamically open and (2) given enough time the energy distributes and will not aggregate.

Let us consider the first assumption. It is an implicit belief that non-living things in the world can exist without any interaction. The counter part of this assumption is often explicitly stated: the living systems are open systems, and exchange energy and matter with the surrounding environment, and these systems are required to work in order to maintain a living state. This is currently held to be one of the foundational principles of complex systems. Ludwig von Bertalanffy, Erwin Schrodinger, Ilya Prigogine are among the best known scientists who get the credit for suggesting this interpretation of a living state. I find this widely held view incomplete, for this gives us a misleading understanding that the non-living systems are closed.

What empirical evidence do we have to suppose that there exists any closed systems in this universe? We do not know any part of the world that is interactionally isolable or any of the interactions which can be said to be free of energy exchange. Then, why hold such a blatently false belief? It is one thing to say that we do need to consider the systems as closed for methodological reasons, or construct experimentally as closed systems as possible to match the 'closed' mathematical equations.[5] But it is another thing to partition the world into two kinds of systems, open and closed. We seem to have no scientific basis for this ontological partition. It is possible to suppose there is a degree of openness, some being more open than others. On this scale, one might jump to suppose that the living beings are the most open. Similarly one might suppose that non-living things are the least open. No. Non-living systems are more vulnarable, for they cannot resist nor repair the results of interactions as efficiently as the living. Thus they can be regarded as more open in certain respects. And since most open means more active, such a state cannot sustain life. Thus, we will see how a counter-intuitive characterization of living state, as more closed than the non-living will emerge in the proposed model.

To make this counter-intuitive claim understandable, though we shall see more elaboration later in the essay, let us consider how living and non-living systems respond to changes in the environment. Non-living systems interact more readily with the environment, while living systems interact in a controlled way. In any case, there are no closed systems in the world. One of the points argued in this essay is to demonstrate that living systems are more immune, therefore more closed, to interactions than the nonliving, for they engage in controlled interactions, and the extent of this control depends on the degree of complexity attained by the systems. All systems, both living and non-living, exist

[5] Indeed an equation implies a closed system.

due to persistant dynamic interaction with the environment, it is not scientific to suppose that only living systems are open. This asymmetry must be given up to see the degree of differences in adaptations of all systems on a single scale.

This does not mean no distinction can be drawn between the living and the non-living. There is a clear qualitative difference between them. One of the objectives of this essay is to clearly demarcate the nature of this distinction. While we wait for the demarcation statement, let us state the similarity statement now: neither of them exist independent of the environment, and neither of them are inert to environmental changes.

The second dogma, that entropy of a closed system will increase to maximum, is more serious than the first, because this assumption is deeply rooted in the science and is considered a universally valid principle. I am not questioning the universality of this principle. This principle indeed is one of the 'drives' of the universe, but there are at least two other drives.[6]

When we study all beings on one scale, we need to regard all the beings as *agents*, as systems that have functional interfaces on them. (By agent I mean braodly a participant in an interaction.) That is to say, there are no beings which are clean spherical point masses. The science which assumed them so, namely classical mechanics, is known today as an approximate truth representing a very simple idealized layer of the world. Quantum physics, which is empirically and experimentally on a firm ground than classical physics, is the most glaring counter statement of the falsity of the claim that physical beings in the world behave like point masses.

The prevailing asymmetry in the assumptions can be seen by considering another case. Let us suppose that in a closed system we let a number of molecules to interact. If the molecules act as mere point masses, we know that the system will move towards highest entropy. But, if we take our gas chamber to be as big as the universe, the probability of heterogenous distribution is not small (see [23]). Secondly, what if the elements are large astronomical aggregates of masses, and not the small gas molecules. The gravitational field at this scale, due to mass aggregation, can not be neglected, further large mass continues to grow due to positive feedback by aggregating other small masses due to increasing field strength. This is possibly the reason why we do not find any randomly distributed walks of astronomical objects, such as stars and galaxies, instead we see a highly organized orchestra of cosmological bodies, symbolizing the higher form of order and not entropy. The order is so high and predictable that we measured our time based on these astronomical 'calenders' until recently till we discovered more precise quantum clocks.

Added to this mass aggregation is the possibility of chemical combination and dissociation, which is due to different functional interfaces of the agents. Thus, if we assume that the initial elements in the chamber are heterogenous agents (elements with functional interfaces like charge or other affinities), the probability of moving to higher entropy is not very high as supposed by the

[6]Stuart Kauffman proposed a fourth law of thermodynamcis in his *Investigations*. I will briefly discuss and compare the proposed position with his later.

second law of thermodynamics. The law assumes an ideal and unreal situation. Thus, if we take these heterogenous agents, multitude of agents and large size of the universe, aggregation and combination as possible events along with distribution of energy, even if the universe starts at a high entropy initial state, a small probable perturbation can disturb the equilibrium and will have regions of space that display chemical and mass *aggregations*. Thus, equal energy distribution among the agents is not a high probability, just as complete aggregation of energy. What is more likely is to find regions of space with high energy distribution, and other areas with high energy aggregation.

In the above situation, the assumptions considered are: let there be (1) heterogenous agents with functional interfaces, (2) let them be in abundance and (3) let there be abundance of space. All these are well established facts in todays science. Therefore it is reasonable to suppose them as given. Given these three initial conditions, whether the world begins in a high entropy state or a low one, the probability of reaching a high entropy state is very very low. Even if the agents are assumed to be homogenous, the positive feedback of mass aggregations is enough to take it away from high entropy. I wonder if these symmetrical considerations, possibility of aggregation and combination along with distribution of energy, went into the calculations of the physicists while calculating the probability dynamics of very large closed systems. Combination and aggregation of elements is as inevitable under favorable conditions as distribution of energy. This other 'drive' is very much in the substance of the world, but did not constitute as a part of the thermodynamics, as the general and scientific theory of interactions.

A good case to consider is the conditions underwhich controlled chemical reactions are possible under enzymatic catalysis. Enzymatic catalysis does not voilate the second law, but cannot predict the possibility of catalysis. This indicates the need to consider other 'facts': the interacting molecules have an active area (functional interface), and their contact with each other is required for a reaction to occur. This contact may happen at an appropriate temperature, probability being low. But this probability can be made higher by enzymatic catalysis. Alignment of reactants' functional interfaces in a captive condition enhances the probability of a chemical reaction under low energy conditions. This possibility suggests that when active area contact happens reaction must occur *independent of heat*. This reaction is inevitable once the contact is established. Currently our understanding is that heat is one of the conditions for a reaction to happen. True. But, its requirement is only to enhance the probability of contact of active areas. If there exists other ways of enhancing the probability, such as controlled alignment of active areas, as it happens in a living cell due to enzymes and membranes, the heat requirement can be relaxed or entirely eliminated. I predict the possibility of cold reactions, if not cold fusion. Cold fusion is a controversial area, often abused as psuedo science. However, in the ontological foundation that I am suggesting in this essay, what is required for a fusion or any reaction to takeplace is to align the active areas of agents. It can happen at any temperature. It is not very difficult to prove me wrong or right by scientific means. Therefore this interpretation is falsifiable.

If heat dependence is eliminated from the picture, then a chemical interaction depends solely on the structure of the agents. This is like any other law of nature: applicable only under the idealized conditions, namely, a condition other than heat making the contact between the agents possible. Constructing such a condition will no doubt need energy, just as creating an ideal friction less surface to demonstrate inertia requires an expensive construction. Just as friction prevents continued motion, heat *actually* prevents combination, and is not a condition for combination. Also to keep in mind is, just as friction, another face of force, can also enable controlled motion, heat can be also enable a controlled reaction. To grasp the underlying principle, we may need to eliminate the impediments as a method.

It is well known today that 'cold reactions' do happen in living cells. Therefore I propose the need to add another principle towards a more comprehensive theory of interactions, may be as an n^{th} law of thermodynamics. A tentative statement can be: an IT interaction is enevitable when contact between the active areas of an agent happens. (The term 'IT interaction' is defined in the next section, for the time being substitute it with the term 'chemical interaction'.)

The considerations discussed above may be taken out of place in an essay on life and cogntion, and better left to physicists instead. Physicists saying "That is biology", and biologists saying "That is physics" will not do. We should explore for unifying foundations. It is relevant to explore an answer to the question: what kind of world gives life and cognition a possibility.

If you grant me the three conditions mentioned above I will construct living and cognizing systems[7]. Note I did not ask for abundance of time. This is because of the conviction that the probability of life under those situations is more, not less. This will remain a mere conviction and not a scientific fact till we do our calculations, and no such calculations are considered in this essay. That is why, this is not a finished model, but *towards* a model.

What are the consequences of giving up the two assumptions/dogmas? The principles of thermodynamics, considered as the most important statements describing interactions within the world, need to be understood in a new limited light. The existing foundations suggest an asymmetry, often called as the time's arrow (Cf. Huw Price 1996). Even if the part of the world that we harbour is asymmetric, science cannot afford to be partial to our experience and world. The very existence of living systems will be interpreted in this essay as symmetric embodiments of time, ontologically rooted in the *re-producing cycles* of biology. Life is a statement of opposition not only to the time's arrow suggested by thermodynamics, but also an opposition to its complete reversal. It is an articulated resistance to the two extremes.

Thus what I find asymmetric in the foundations of science is the neglect of the functional interfaces of the agents on the one hand, and the effects of chemical combination and physical aggregation counteracting the energy distribution. During the course of this essay, we shall return to a discussion of

[7]This can be a fruitful program to investigate within artificial life, a flourishing discipline as a part of the emerging sciences of complexity.

these assumptions, and how they need to be supplemented and corrected, and see how they misled our understanding. More consequences will be discussed during the course of the essay.

4 If there is a process, there exists a counter-process.

The approach to these modified foundations is obtained by following a rigorous theoretical method. The method followed is to dilute all partitions in the ontology, use the same scale of measure as much as possible for all dimensions, and symmetrical argument without bias or predetermined convictions.

The reasons for assuming that there are no closed systems in the universe is similar to Galeleo's assumption that there is nothing like slowness. There are bodies that move fast or those that move slow. So if one wishes to measure, we should not partition the world into moving-things and non-movingthings, as Aristotle did. Instead we keep all objects on a single scale and compare their movement. Similalry, since there are no closed systems, there are systems that are less open and those which are more open. The strategy therefore should be to keep all the systems on one scale and try to explore for a method of comparing their openness. That is why we should rest the ontology where there is a partition between non-living things and living things.

The other method followed consciously in constructing the model is inverse reason, a form of symmetry or balance in thinking style. Let us hear again what this means from Galileo:

> If contraction and expansion [*condensazione e rarefazzione*] consist in contrary motions, *one ought to find for each great expansion a correspondingly large contraction*. But our surprise is increased when, every day, we see enormous expansions taking place almost instantaneously. Think what a tremendous expansion occurs when a small quantity of gunpowder flares up into a vast volume of fire! Think too of the almost limitless expansion of the light which it produces! *Imagine the contraction which would take place if this fire and this light were to reunite*, which, indeed, is not impossible since only a little while ago they were located together in this small space. You will find, upon observation, a thousand such expansions for they are more obvious than contractions since dense matter is more palpable and accessible to our senses. We can see wood and see it go up in fire and light, but we do not see them recombine to form wood; we see fruits and flowers and a thousand other solid bodies dissolve largely into odors, but we do not observe these fragrant atoms coming together to form fragrant solids. *But where the senses fail us reason must step in*; for it will enable us to understand the motion involved in the condensation of extremely rarefied and tenuous substances just as clearly as that involved in the expansion and dissolution of solids. [10, p. 60]

This illustrates his symmetric thinking style. If a body is losing weight then there must be that contrary balancing phenomena where the body would gain weight. If a body is sinking in water, then imagine a media other than water where the body would begin to float. If a quantity is successively diminishing in a process, imagine of that quantity which at the same time is increasing. If there is a quantity progressively increasing in one direction, think of another quantity that would progressively increase in the opposite direction. If some thing continuous to remain in a state without variation, it must be in the state of equilibrium where the contraries are invariantly at work. If *by fact* we know one side of the process, we can construct *by reason* the other side of the process. The belief in complete reversibility and symmetry of the world order is the only guiding principle of scientific construction, which interestingly also generates conservation principles. The relation between conservation principles and symmetry are now well established in theoretical physics, thanks to Emmy Noether.

Thus, the principle of balance seems to be at the very core of modern science. I have only tried to apply this thinking style as rigorously as possible to the domain of biology, which is ridden with partitions. It is very well known that one of the key factors in the chemical revolution was the use of principle of balance by Lavoisier to prove that the masses of reactants and products must remain conserved. Detailed case studies of inverse reason in the history of science are worked out in [18].

I must mention that the very idea of algebra is all about the application of the principle of balance. Modern science is inconceivable without algebra, an essential tool of mathematical science. Modern algebra is formal, rigorous and content neutral, in the sense that the operations and the structures built by employing its methods require specific interpretation in the context of application in order to make sense of the form. One of the fundamental principles of algebra is based on the 'principle of balance': when we add or subtract anything to both sides of the balance, the equilibrium of the system remains unaffected. This is the principle that allows us to solve algebraic equations of various degrees of complexity. By adding, subtracting, multiplying or dividing an equation on both the LHS and the RHS of an equation we solve and simplify equations, and without this method there is nothing like algebra. This transformation of an equation is as fundamental to algebra as the rule of detachment is to deductive logic. It is usually proved as a theorem from other axioms, commonly called the *law of cancellation* in formal systems of arithmetic. Terms in an equation can be moved from LHS to RHS or vice versa by using this law for solving algebraic equations. I have called this style of scientific thinking as *inverse reason*, and proposed it as a logic of scientific creativity or construction in my thesis[18].

Following this style of thinking, if a process is possible in the world its counter process is also possible. In physical and the so called non-living systems, the process and the counter process do not exist in one place, but somewhere in the universe. But in living systems, the process and the counter process exist *within*. This is what is claimed as the root of autonomy or control in biological systems in this essay. We see such composition of counter processes all the time in biological systems. This was pointed out by Claude Bernard and Sherrington, who laid the foundations to understand homeostasis—a state of dynamic equilibrium. I followed a similar path, eliminated asymmetrical considerations in thermodynamics, and added the 'weights' on the other side of the pan to achieve the balance.

In what follows, I propose a model which gives life and cognition a possibility by following this balanced foundation. This alternative foundation can *assimilate* the physical non-living space effortlessly, while providing an interpretation of life and cognition based on the fresh logical space. During the course I will find affinities and relate my position with the innovative proposals already made by Jean Piaget, Ilya Prigogine, Manfred Eigen, Humberto Maturana, Francisco Varela, Marcello Barbieri, Stuart Kauffman, Marc Bedau to name a few. While they do break new ground in arriving at a few of the general principles of biology and complex systems in general, they continue to work in an ontology still ridden with some classical dichotomies. Nonetheless their campaign at least established the study of self-organization and complex systems as a respectable scientific research program. The objective of this essay is to construct an ontology based on minimally, but sufficiently, complex systems to understand the genesis, structure, dynamics and evolution of complexity.

5 The world is the totality of Becoming-Beings, not things.

In this section an introduction to the ontological foundation of the proposed possible world is presented. Consider or imagine a world made on the basis of the following postulates. Important terms used in the postulates are defined first.

Definitions

1. **Becoming-Being** is a Being[8] when the changes (becomings) within the Being are responsible for its existence.
2. **Identity:** The relational invariance of internal interactions defines the identity of the Being.
3. **Identity Preserving (IP) Interactions** are those that do not transform the relational order of internal interactions, but may change Being's positional relation to other Beings.
4. **Identity Transforming (IT) Interactions** are those that transform the relational order of internal interactions, making the original Being to become another.

[8]When the term 'being' is used as noun I will capitalize, to distinguish it from the usage of it as a verb.

Postulates

1. **Multiplicity and Heterogeneity:** There are abundant Becoming-Beings, and are of different kind.

2. **Differentiability:** Each Being of the world has an identity of its own, that is to say each Being can be distinguished from the other.

3. **Openness:** All Beings interact with the environment (other Beings). Alternatively, there are no closed systems.

4. **Perturbation:** Each interaction transforms the Being.

5. **Invertibility:** The transformed Being may invert to the original state of Being if it has processes within that can repair the perturbation caused.

6. **Being and Existence:** Only those Beings that can invert the perturbations maintain their identity in an ever changing environment. A Being exists in an environment if and only if it has the ability to repair the perturbations caused by the environment.

7. **Mutation and Decay:** When IT interactions are not inverted by the Being, Beings mutate or decay into other Beings.

8. **Composition:** A Being is composed when a process and a counter process form into a relational loop.

9. **Interactions:** The world is a totality of interactions not things.

These postulates define the phase space of the possible world in general, and not the living world. All the above definitions and postulates will be elaborated with actual world examples in the subsequent sections. In this section I will explicate the postulates.

It follows from the above mentioned definition that in the absence of the activity within the Being, the identity of the Being is not possible, and the activity within the Being is to counteract the effects of other Beings. This circle of explanation forms the methodological unit of the model being proposed. We will revisit this pattern of thought again and again in later sections.

There are no unchanging things in the world, not because Beings are constantly forced to change by some external Being, but because *change is Being*. Does it sound like Heraclitus's world of flux? Possibly. But please wait before jumping to label the model as this or that, since I will be clarifying the nature of identity of Being below. Another way of saying this is: *The world is the totality of events, not things*. Events are the substantial *reifiable* units of this world. Since every event must be an interaction, let us consider interactions as the substance of the world.

In this kind of a possible world the *only* possible identity is recursion, periodicity, regularity, concurrency, sequence, or some such ordered relation between the interactions.[9] Interactions are *noticeable* differences of this world. The differentiation of these differences, the pattern of interactions, constitutes a *Being*. *Identity refers to the order of change and not to things*.[10]

If interactions cease the Beings disappear. The relentless activity that takes place at a *micro level* keeps the *macro level* identity of the Being invariant. In other words, the continuous *becoming* of the lower-level *Being* produces an emerging identity at the higher-level which we may call a *system* or a *structure*. But the internal activity is not autonomous, but goes on as a response to the environment of the Being. Thus a system is at the apparent edge of its substance (microcosm) and environment (macrocosm).

Since, becoming in the Being is necessary to maintain the identity of the Beings, we can say becoming makes Being possible. But all the activity or changes are nothing but interactions among Beings. In this sense we can say that the world is the totality of *Becoming-Beings*.

From a phenomenological point of view, interactions constitute phenomena. From a logical point of view, to be is to be an instance of an interaction and interactions are the only *individual* things that are posited to exist in the world. Let us recall Quine's famous aphorism in his essay on ontology: "To be is to be the value of a variable", and in his ontology individuals alone can be considered existing. Following Quine's advice for constructing an ontology, interactions become individuals in the current model.[25]

In a world where there are no interactions, no objects or systems can exist. It is not proper to think that interactions have a causal role for the existence of systems. Interactions do not cause systems, interactions can cause only interactions. Since it is held that systems are apparent, a real thing cannot *cause* an apparent thing. What then is the relationship between interactions and systems? As stated above, a system is a pattern of relationship between recurring interactions, and therefore it is a *state* of interactions, not a mere collection of them. It is a condition of being related to each other. So the real cause of a system is the *relations* between the interactions and not the interactions themselves. This, to my mind, is the proper relationship between a part and a whole. Relationship between the parts constitute the whole and not parts themselves. We were told by several scholars who argue from the systems' point of view that the whole is greater than the sum of its parts. True. *A whole is the product of the relationships between its parts and the environment.* This is our version of the aphorism. In the forthcoming sections we will discuss more on the nature of the relationship between the parts of a system. It is enough, at this point, to realize that interactions are not the causes but parts of the system, for they are the individuals in the ontology.

[9]It is important to realize that the notions of recursion, periodicity, concurrence, regularity, and sequence presuppose a notion of *time* and *space*.

[10]Since a collection of inter-related events or interactions is generally understood to be a process, a Being is at its core a process, or a process of processes. While this view sounds like the process philosophy of Alfred Whitehead, I did not adopt his views consistently. It is possibly more akin to Leibniz's relational world.

Consequently, the emerging system at the higher-level is *formal* and not *substantial*. Ontologically there exists only interactions. There are no levels of interactions, and the *plurality of levels* (hierarchy) and other structural details to be found in systems is believed to be relations among them. The ultimate lower most interactions may or may not exist in our observations, they may therefore be posited theoretically to explain what is apparent to us.

The structure-less ultimate interactions are too flat, so we begin to carry on our task with what we constructed out of their relationships, namely the formal systems. When we say that the world is the totality of Becoming-Beings, we are saying that *the world is the totality of systems, not atoms*, with the understanding that a system stands for a state of interactions. There is minimal complexity deep at the foundation.

A set of Beings get together in an interacting relationship to form a system within a stabilizing environment. Being cannot be defined independent of its environment, because the internal order of the Being is a response to the environment. In a perturbing environment systems maintain their identity by replacing or inverting the component interactions by others of its kind, and not by rigidly holding the same component objects.[11] Since it is the relations between interactions that are real and not the constituents, the system appears invariant for an external observer. This may appear counter-intuitive because the replacements or inversions are not apparent in many of the macro-systems that we encounter regularly. We shall see more specific and familiar examples later that will make this general account more clearer.

Let us recall that the system is not identified by the individual interactions but by the relationships between them — a state of interactions. This allows the system to maintain its identity even if one of the individual components is replaced by another component of its kind. This is one of the central points of the position held here. The identity of the Being as defined here is almost similar to the notion of *organizational closure* developed by Maturana and Varela. We will return to this interesting idea in the context of autopoisis and metabolism later.

Being, therefore, is a function of invertibility, and repairable perturbations are a kind of *feed* for the Being. When we say, a complex system, like a living organism, depends on energy to maintain itself, the energy is actually the perturbing factor of the Being. This is how any Being is intricately related to the environment at all times.

[11]The philosophical school called functionalism emphasizes the relational fabric of things and not the substantive properties of things which participate in the relations (Cf. e.g. Churchland and Varela). My position clearly has affinities with functionalism in the sense that the substance replaced depends on its ability to play the functional role, namely the interaction.

6 One kind of perturbation of a Being is identity preserving interaction.

If interactions are the basis of the world, then a theory of interactions should be able to account for the core of the world. In this and the following section I will elaborate the two kinds of interactions: identity preserving (IP) and identity transforming (IT) interactions. These interactions form the basis of any account of Beings.

IP interactions do not transform the relational order of internal interactions of a Being, but may change Being's positional relation to other Beings. IP interactions resemble physical interactions that come under the scope of classical physics, which deals point-masses moving or interacting with each other. It is assumed that the energy is conserved in these interactions, and the systems that contain a population of point-masses follow the laws of thermodynamics.

If IP interactions are similar to physical interactions, one may ask, why not call them so. It is because the term 'physical' is not always used exclusively for the phenomena dealt by classical physics. I want to exclude from IP interactions some of the events that take place in quantum physics, and chemistry. The term is also used, e.g., by materialists for mental or biological interactions, because for them anything natural is supposed to be physical. In this sense being physical is same as being real. This is not the kind of meaning that I intend to associate with IP interactions. Therefore let us not not associate IP interactions with all that is physical, but only those interactions that classical Newtonian physics deals with and also those of relativist mechanics of both macroscopic and microscopic domains. Since readers are familiar with these phenomena, it helps to understand the current model, if IP interactions are associated with classical Newtonian and relativistic mechanics.

When we say that during IP interactions the identity of the Beings or systems remains unaltered, we are not saying that these interactions are not about change or do not bring about change. In fact there is nothing in the world that is not about change, for we assumed that change is real. The Beings do undergo change in position (displacement), change in velocity (acceleration) and other dynamical variables. These changes are not about the Identity. The identity referred here is of the internal structure of the Being, it is about its complexity of the so called "substance". This aspect of reality is *methodologically bracketed* in a typical discourse of IP interactions, for substance is irrelevant for studying mechanics of bodies.[12] Galileo—who was instrumental in popularizing this method—says, the substance is an impediment to a proper understanding of the "book of nature". Whatever be the substance with which they are made, is of no consequence to understand the motion of bodies and interactions with others. Since the world view of classical and relativistic mechanics is familiar terrain to

[12] Science approaches reality only by this way of ignoring some aspects by creating idealized and imaginary spaces. Science is about the idealized physical systems and is about the phenomena tout court only by indirect means and has no direct access. (Please see the detailed arguments and a rather complete explication of these views in [18].)

most of us, I need not elaborate on this any more.

From the point of view of the current discussion, there is one important characteristic of IP interactions that we need to talk about. Since we declared that the world is made of multiple Beings (the principle of multiplicity), we need a model that accounts the IP interactions among them. This is where the laws of thermodynamics—an extension of classical mechanics to machines and systems with several point masses—play the role. The two of its principles are well known: The energy is neither created nor destroyed, and the disorder or entropy of a closed system increases till it reaches equilibrium or the maximum value. IP interactions obey these laws. Biological systems seems to be working against the second law of thermodynamics. Schrödinger in his famous essay, *What is Life?*, made the first serious attempt to understand the kind of physical conditions that make life possible particularly from the point of thermodynamics and statistical mechanics. We will return to some discussion on this after we prepare the ground for the current model. At this place it is sufficient to note that IP interactions follow not only the laws of mechanics but also the laws of thermodynamics.

Before we move to the next section, let me state the connection of IP interactions with that of living systems or all Beings for that matter. Living systems are perturbed by the IP interactions both from within their internal environment as well as from the external environment. Heat, light, and gravitation are the most common perturbing agents of living systems. These perturbations may at times lead to IT interactions.

7 The other kind of perturbation of a Being is the identity transforming interaction.

Under certain conditions when the IP interactions perturb the systems, it is not merely the dynamical variables that get altered, the substantial or material aspects of the Beings involved get transformed leading to IT interactions. For example, under certain (thermodynamically favorable) conditions when a system called *hydrogen* collides with another system called *oxygen* could produce another system called *water*. Under what conditions such changes take place cannot be understood without considering the nature of the identity of the participating systems, and the environmental conditions. Let us recall that identity of a system is defined as the relational invariance or the order of internal interactions. This is essentially the structure of the system constituting the given material. The structure of the participating systems in IP interactions was systematically kept out of consideration, *but* while studying IT interactions it is *essential*. The nature of the interaction, and the kind of transformation depend on the structure of the participating Beings. For example, valency of chemical elements is a determining structural property that accounts for chemical bonding.

We study these kind of interactions, e.g., in chemistry, quantum physics and biology. The reason why we cannot call them only as *chemical interactions* is because there are several IT interactions that take place in the subatomic, and can as well be found in supra-biological, domains. But it suffices here to mention that all chemical interactions are IT interactions, but not vice versa. Though the concept is defined more generally, for the purposes of this essay we will consider only the chemical interactions, since all biologically significant IT interactions are chemical in nature.

In a closed environment when IT interactions take place there will be a change in free energy, and whether this change is positive or negative depends again on the structure (identity) of the systems involved in the interaction.

We know that even in every biological cell a large number of IT interactions go on. Almost all the metabolic reactions that we know of are IT interactions. These interactions are not only induced by internal factors but also external factors. Living organisms necessarily depend on a chemical environment for survival, that is to say—in thermodynamical terms—an environment where there is a change in free energy. We are generally gives to this understanding that no organism survives exclusively on the energy that comes from IP interactions. We will see later that mere heat can maintain living organization. Though living organisms are generally said to have a dependency relation with IT and IP interactions, the better way of explaining the relation is by supposing that the interactions have perturbing relationship with the living organization. Autotrophic plants and several bacteria too require water, minerals in addition to sunlight for their survival. Actually, dependence and perturbation are intrinsically related in the case of biological systems. Though the term 'perturbation' has a negative connotation, in the absence of some of the perturbations organisms do not survive. This is because the identity is a function of the interactions and the interactions are necessitated by the perturbing environment. In this sense some perturbations are necessary for the survival. It is these necessary perturbations that form part of the organisms' external dependencies such as food and energy. It may sound utterly counter intuitive to consider food as a perturbing factor, but this is the only coherent explanation that we will find in the model that takes care of every biological phenomena. We will return to this interpretation later with specific examples particularly in the context of explaining autonomy.

8 A Being is a product of counteracting both identity preserving and identity transforming interactions.

In an environment where systems undergo only IP interactions the direction is towards maximum entropy (order to disorder) as per the second law of thermodynamics. On the contrary, in the biological domain there seems to be a movement from disorder to order. Based on several studies and interpretations beginning from Schrödinger, Bogdanov, Bertalanffy, followed by Prigogine and various other cybernetic approaches it became clear to us that living systems

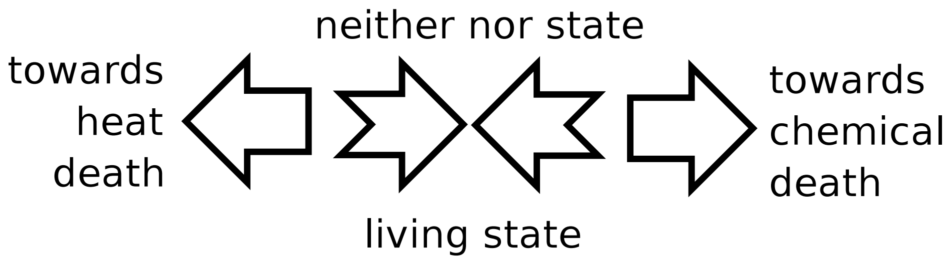

Figure 1: A Living Being is a neither-nor-state counteracting the two possible interactions

are *thermodynamically open but organizationally closed* by keeping themselves in a state of far-from-equilibrium by a steady flow of energy and matter (other Beings) into the system and out of it. By supposing that living systems are open and the system does work to increase the order, the apparent contradiction with the laws of thermodynamics gets reconciled. In this widely held interpretation, living systems are described as those that *oppose* disorder by spending energy (working). In the absence of this opposing activity the cells of living systems disintegrate. This recieved view is a partial truth.

One of the main ways of counteracting the increase in entropy is by increasing chemical bonds (by IT interactions). By trapping the energy within the bonds the order within the cell increases. If the direction of life is only to oppose entropy then during the course of evolution life would have produced crystals by compactly storing a large number of macromolecules harboring large number of bonds, and therefore by trapping a lot of energy more and more order gets generated. Such accummulation of macromolecules beyond 'necessity' is a seen among plants, and to a lesser degree in animals. But more complex living systems, animals, are not driving in that direction. On the contrary, what seems to be happening among animals is conserving and maintaining whatever identity exists. In the absence of this conservation the Being transforms into another Being. This is because there exists another 'misery', apart from the direction of thermodynamic equilibrium, another direction of, what may be called, the *chemical death* in contrast to the *heat death*. This is reflected in the world in the formation of chemical bonds. Under certain conditions the Being cannot help but produce complex chemicals. As noted in §3, when a chemical reaction cannot be stopped when the conditions obtain. In a living state, chemical reactions also need the to be controlled.

Though formation of chemical bonds appear like decreasing the entropy of the system, and thereby increasing the order, the Beings that are involved in the interaction lose their identity. As a whole if the identity which is defined as the organization of a living being is transformed, there can be two consequences. One is a mutated Being, and the other is death or disintegration. The former is possible when every change may not be deleterious, the latter is possible when the system cannot repair every change. Living Beings are not increasing order during their existence, instead they are conserving the identity. It is my central claim that complexity should not be confused with increase in cold order. We will return to this argument later.

One of the important aspect of living systems is conservation of identity or *organizational closure*—to use the nice term coined by Maturana and Varela (see section 11). Since chemical interactions are also perturbing in nature it is necessary to counteract them. If there is no such counteraction then Beings must be speciating too fast, or Beings should disintegrate. But that is not what we see. Neither is the case that species are formed so spontaneously nor do we see their disintegration. Therefore life cannot be conceived without conservation of identity.

Metabolic interactions therefore must not only be working against thermodynamic equilibrium but *also against chemical changes*. As stated in the §3, the other enevitable interactions, chemical changes, must happen. This 'drive' is also damaging to living organization. Living state is therefore defined as a product of counteracting *both* identity preserving and identity transforming interactions: a *neither-nor-state*. Metaphorically it is like a tug of war between thermodynamic equilibrium and chemical combination. However, the state is not like tight-rope walk, for it is not such a vulnarable balance. It resists a long range of perturbations of both kinds, and some perturbations have more than one repair mechanisms. Prigogine's idea that self-organizing systems are far-from-equilibrium is therefore a half-truth, for such states don't last long and they collapse very easily. Kauffman's definition of living state as being at the edge of order *and* chaos is much more closer to truth. Using his language, I propose that *biological order* is on the edge between *chaos* on one side and *crystalline order* on the other. What then is the mechanism of maintaining the identity by opposing the two kinds of "death", and the nature of the living state?

9 Beings are composed according to the principle of included contraries.

Let us recall briefly the description of the constructed world so far: In an environment which consists of several Beings that are open to two kinds of interactions, an interaction without perturbation is impossible, and the world is actually made of interactions and not things. A relational order of interactions constitutes the Beings or systems of the world. There are only two kinds of interactions, IP and IT, and in the IP interactions the dynamical variables get altered and in IT interactions the relational order of internal interactions of the Being get altered.

In an ever perturbing world there exists one possibility for the existence of systems, however long or small their duration may be. This is when two interactions with opposing effects get together to form a relational loop. A becomes B after a perturbation and B becomes A after another perturbation, and if this loop continues for a while, if not eternally, we get a Being of AB complex. This requires that the perturbing agents too are available in abundance within the environment—satisfied by the principle of multiplicity. In a world of this kind a stable Being cannot be conceived without a conducive environment. This is the nexus between the possible Beings and the environment, where the environment is nothing but a population of other Beings. But, this is also the principle of composition of Beings: *A Being is composed when a process and the counter-process form into a relational loop.* This is the construction logic of Beings: *the principle of included contraries.* Propositional systems (belief systems) are constructed on the basis of *principle of excluded middle* according to which a proposition P and its negation $\bar{P}$ are never part of the same system. According to the principle of included contraries, the principle of physical systems, a process P and its inverse $\widetilde{P}$ are part of the same system. If the Beings exist as a function of its interactions with the environment, it follows that their existence is nothing but their adaptation to the environment.

When it was stated that the world is a totality of systems, I meant, systems composed according to the principle proposed above. We began with the supposition that interactions are the stuff of the world, but interactions happen between systems. Systems themselves are then said to be composed of opposing interactions. Aren't all these suppositions confusing, if not contradictory? The stand taken in this model is that either of them cannot be *understood* without the other. I mentioned 'understood' because the interdependence is epistemological or semantic rather than ontological. Reconciliation is required for us, who hold beliefs, not for the world out there.

10 Dialogical invertibility is the basis of life.

Invertibility is a state of the Being where the Being can revert the perturbations caused by other Beings (environment). All Beings have this ability not necessarily the living systems. If you recall, we are motivated in building a possible world where life and cognition are possible, and physical systems in this model will be explained as a limiting case of the world. Living Beings can be clearly distinguished by other important structural embodiments, which will be discussed later. Different Beings can be distinguished on the basis of a measurable *degree and order of invertibility*. The physical basis of invertibility is within the very nature of Beings as explained in the above section. Thus the model so far constructed according to the twelve principles is a generic model for the entire world. All Beings are in a state of inverting both IP and IT interactions in varying degrees. This counter intuitive idea that even non-living Beings, like atoms and elementary particles, are Beings composed according to the principle of included contraries requires more elaborate space and time, hence this will not be discussed here. Here I will elaborate how living systems manifest invertibility and neither-nor-state.

Let us look at the kind of stuff living systems are made of. Let us consider water, foremost of all.

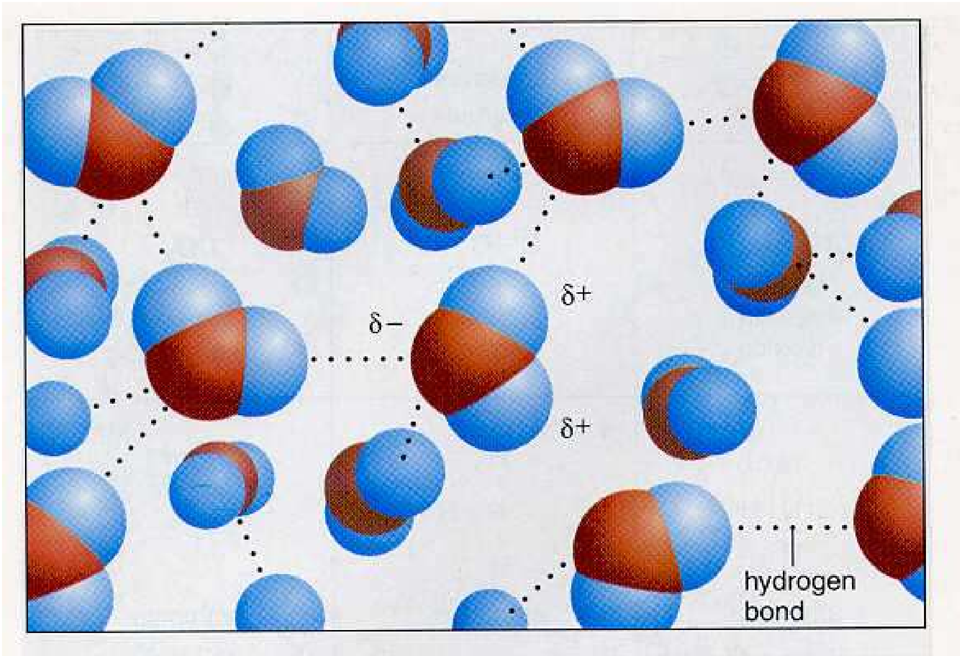

Figure 2: Water: Enabling space of life

Liquid state of water is a life enabling space, a paradigm case of neither-nor-state. Though, two atoms of hydrogen and an atom of oxygen form a water molecule by covalent bonding, the extraordinary properties of water are mainly due to the *several* molecules of water interacting with each other. In a large pool of water molecules each could perturb the other. Apart from the collisions (IP interactions) between them there are also chemical interactions (IT interactions) in the form of hydrogen bonds between them. But in a liquid state of water, the weaker bonds form and break at a constant rate. Association and dissociation of molecules by hydrogen bonding constitutes the two opposing IT interactions representing the P and $\widetilde{P}$ of the system. Here we are talking about the interactions among water molecules and not between hydrogen and oxygen within each molecule of water. In this special case, the perturb*ing* system, perturb*ed* system are in the same environment, and a large collection of looping interactions maintain a wonderful life enabling space. This gives the liquid state of water one of the necessary conditions of life with a high specific heat making it a good heat buffer. Heat in the environment (nothing but the IP interactions of water molecules themselves) acts as a perturbing factor on liquid water breaking the hydrogen bonds. In a large pool of water molecules another molecule replaces the role played by the perturbed molecule, and so on. So the mechanism actually is *replacement* of the perturbed molecule by another of its kind. Thus water manages to resist the heat perturbation for an extraordinary range. This is, so to speak, an emergent property of water. A good example of the effect of abundance.

Water, apart from being a heat buffer, is also a pH buffer. Water can be said to be neither an acid nor a base. It has an abundant pool of H_3O^+ ions and OH^- ions which can neutralize the negatively and positively charged groups of other chemicals (perturbing agents) when added to water. In a living system, many other cations and anions in abundance create a supplementing buffering environment for proteins and other metabolites. All known pH buffers are aquatic. In fact the pH scale is calibrated by taking water as a base. For all *in vitro* examinations of biochemical interactions, the first condition is to create a buffering environment suitable for the reaction at hand.

I consider it therefore important to define another higher level of interactions called *dialogical interactions*. One characteristic of these interactions is *frequent inversions* comprising a process P and its inverse process $\widetilde{P}$ and the perturbing and perturbed components are physically located in the same system. Though energy is required for each of the reactions, since the reactions happen in a loop (invertible) external energy dependence is very very minimal. The released energy is used up internally, instead of loosing it completely to the external environment—minimizing dissipation. We will see later that it applies not only to energy but applies also to recycling of matter (metabolites) released as products in a very complex dialogical interactions that take place inside the cell.

These dialogical interactions illuminate a neglected aspect of living system. These buffer states produced are actually the best 'Maxwell daemons' nature could produce. These interactive loops involve very small quantifies of energy, and the energy required for these changes is readily available from the surrounding environment. Since energy requirement is small and is cycled within them, very little of it gets dissipated. To understand the significance of these little daemons let us consider the case of a frozen cell. In the frozen state most activities of life come to a halt. When such a frozen cell is slowly brought back to life, by gradual heating of the environment, the living state returns. At this moment the cell took into it only the 'feed' of heat. Most of the frozen enzymes are back into action due to this source of energy and not from the stored ATP or catabolism. The latter is ruled out since these are themselves enzymatic reactions. Thus an enzyme can be kept active by merely feeding heat. Of course excess heat will denature them. Usually biochemists do not consider heat as a source for doing biologically meaningful work. But, this example suggests that mere heat can make the cell do lot of work. Heat in the environment does play a biologically significant role in maintaining the living state. Though heat alone cannot keep the cell active for long, it is surely one of the necessary conditions. Biochemists do not deny this, but they do not explicitly say that heat is a source of energy for biological systems. The only physical form of energy they admit explicitly is the energy trapped by photosynthesis by green plants from sun light.

This is possible because of an abundance of little feedback loops. If dialogical interactions happen whenever feedback loops are possible, why burden with another term 'dialogical interactions'? Reasons are similar in kind to those given for introducing the terms 'IP' and 'IT interactions'. The term 'feedback loop' is not used in all the contexts where dialogical interactions take place, e.g., the case of water. Later we shall see that enzymatic nature of proteins is also due to dialogical interactions. We also have another category of reactions in chemistry called *reversible*. They constitute a proper subset of dialogical interactions. But we do not normally call them feedback loops. However all the dialogical interactions that we may encounter may not be reversible reactions. Therefore, instead of extending the meaning of extant terminology, which may lead to confusions, I think it is better to introduce new terminology. Also since we have a defining criteria which will be useful to identify various instances across all domains, the use of a new term 'dialogical interactions' is justified. The most compelling reason for introducing this kind of interactions is that they form the basis for distinguishing non-living invertible systems from those of living. While invertibility is the logic of Beings in general, *dialogical invertibility* is the logic of living Beings.

This interpretation may provoke a question: Are substanaces like water which exhibit dialogical invertibility living? Dialogical invertibility, as seen in water, is one of the necessary conditions of life, not a sufficient condition. There is another kind of dialogical invertibility. The other kind is when a single large structure (macro-molecule) has several action zones (multiple interfaces). This is widely seen in biomolecules such as proteins and nucleic acids. In some cases the interfaces in a single molecule have amphipathic and/or amphoteric properties. When a single system attains two opposing properties one of them effects the other and vice versa. This provides a possibility for one *part* effecting another part of the same molecule. Both these situations have life enabling effects. We saw the former case earlier in the discussion on how water acts as an excellent inverting (buffering) medium. The latter provides the possibility of a single system having several interacting sites (active sites) that can produce functional changes, but *without undergoing any change in the identity* (primary structure) of the Being. Water may maintain an identity for a wider range of perturbation, there is no marked difference in its behavior. On the other hand the macromolecules in the protoplasm change their behavior without undergoing any change in the primary structure. Interestingly when we have a Being that doesn't undergo structural changes, but displays behavioral changes, we arrive at a very special feature. This is the foundational character of living state. To the question "What makes life possible?", my answer is: *A Being capable of displaying behavioral changes without undergoing change in identity.* This flexibility is also an index of adaptation we find in the living world.

Why is the identity of Beings interacting dialogically doesn't change? Because the dialogical interactions are characterized by invertible weaker bonds, like hydrogen, hydrophobic, hydrophilic bonds, or van der Waal forces. The Being participates in interactions without changing itself: a state where, so to speak, a *dialog* is possible: A perfect condition for the *plasticity* of life. The energy required for enzymatic catalysis, for example, lowering the activation energy of the reaction is actually derived from weak interactions (hydrogen bonds, van der Waals, hydrophobic and ionic interactions)[14]. It is very interesting to note that while the large molecule became *one* by strong covalent bonds, a single large molecule contains multiple number of weaker bonds which are responsible for the display of behavioral dynamism of large polypeptides: changing shape by folding and unfolding, wiggling, vibrating, displacing (and even walking), contracting, catalyzing, binding to pathogens, receptor-ligand interactions etc. Even more interesting is to note that none of these seemingly mysterious events violate the laws of thermodynamics. All these changes of large molecules do require energy which comes mostly from weaker bonds making them invertible after the function. Since this energy is not easily dissipated due to buffering property of the media a lot of recycling takes place within the cell. Thus energy dependence of these dialogically invertible interactions is *maximally* minimized. Despite the low energy bonds they do produce noticeable *functional* changes in the Being without any change in its identity. Dialogical interactions thus constitute the *phase space of living state*. From the core to the periphery of living world, they are ubiquitous. This is the reason for the energy efficiency of living organisms, the only Maxwell daemons nature could admit.

Protoplasm of a cell is neither a liquid nor a solid, but a colloid. This colloidal state is attributed to large size solutes the cell contains. We have looked at the neither-nor character of water earlier. Let us also look at some of the biomolecules of the same nature which constitute the very core of every living cell. Amino acids, the building blocks of proteins, are known to be *amphoteric*, possessing both basic and acidic properties in a neutral aqueous medium, where they exist as *zwitter ions* with the NH_3^+ and the COO^- as the two polarities. Amphoteric nature of amino acids also contributes to the buffer properties of protoplasm helping in resisting changes in pH. This property also makes proteins amphoteric, making them to possess a large number of positive and negative charges. The adjacent H of NH and O of CO of a polypeptide also form hydrogen bonds producing the characteristic secondary structure of proteins. These bonds are sometimes formed between two protein molecules, and sometimes between two positions of the same molecule. This is an important structural property of the substance of life including biocatalysts (proteins and RNA (ribonucleic acid)). These secondary interactions help the very long polymers to fold to produce different shapes of structures. These are the polymers that are capable of enzymatic action. As explained above, the weak interactions within the same molecule are actually responsible for the enzymatic function: lowering the energy barrier of biochemical reactions. It is no coincidence that enzymes are those substances which participate in interactions without their identity changed. Enzymes mostly form invertible complexes with substrates and products. In fact a catalyst is defined as that reactant which remains unchanged after the reaction.

Another characteristic of the protoplasm is that of all the organic molecules possible in a scale of most reducing to the most oxidized states of molecules, it is only the middle kind that find a place within. As shown in the figure 3 it is the aldehydes and ketones that perform most of the 'drama' in carbon metabolism.

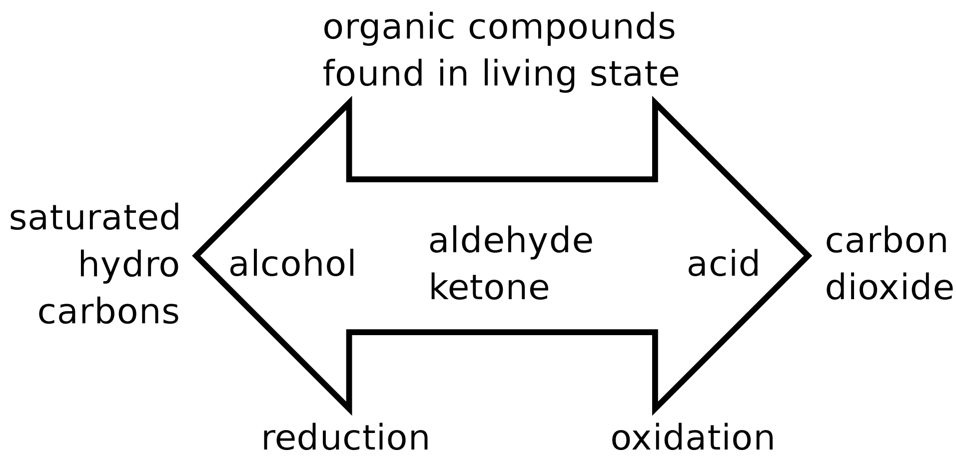

Figure 3: The oxidation and reduction states of carbon. Extreme oxidation and extreme reduction of carbon are avoided in living state. All of the metabolites in the living system are from the middle space.

Another very important biomolecule constituting the core of living cell is phospholipid, the building block of all cellular membranes. Phospholipid is another neither-nor system: it is hydrophilic on one end and hydrophobic on the other. A large number of phospholipids *self-organize* to make membranes. Again there are no covalent bonds between the phospholipids, but only weaker Van der Waal interactions. These structures are also not produced by spending high feed of energy but by hydrophobic and hydrophilic affinities between them. The formation of phospholipid bilayer is often cited example of self-organization. Coupled with membrane proteins and other transport proteins cell membranes perform several regulatory activities. Most important function a membrane performs is to create a partition between the internal aquatic environment (protoplasm) and the external environment. Water diffuses into the cell and could cause an irreversible perturbation if it is not sent out. Osmoregulation happens by forcing water out to keep a balance.

Maintaining balance of water, salts, sugar, several other metabolites, is usually carried out by counteracting processes. We shall see some examples. Establishing stability and control by counteracting processes is not a new idea in biology. It is the characteristic of the scheme of thought initiated by Claude Bernard and Charles Sherrington for understanding the physiological processes in living systems. It is rather routine to think as a biologist that metabolic reactions constitute anabolic (associative) and catabolic (dissociative) processes. A right balance of them maintains a constant flow of metabolites, and when anabolism is in excess of catabolism growth and development take place. And death or disintegration is accounted as an excess of catabolism over anabolism. A paradigm case of homeostasis—maintenance of the level of glucose in mammalian blood—

happens by the two counteracting hormones, glucagon and insulin, in controlling the two counteracting processes, glycogenesis and glycogenolysis respectively, is also well established. Several other hormones also work in a similar pattern. The central nervous system in vertebrates is another classic case. The peripheral nervous system constitutes somatic and visceral, where the former is voluntary and the latter involuntary or autonomic. The autonomic nervous system in-turn has sympathetic and parasympathetic divisions, have opposing effects on organs they are connected to in the viscera. Most vertebrate physiology text books give a table containing a big list of sympathetic and parasympathetic effects of each organ. Even the somatic division of nervous system controlling mostly the muscular movements are also organized to produce counteracting muscular movements as follows: when one muscle contracts a part of the body bends, and when another muscle contracts the bent part of the body restores to original position. This is the general logic of control irrespective of whether it is of metabolic nature or of movement or any action for that matter. The list of such examples can go on, but the point to remember is to understand the conditions that make control possible—which are action and counteraction.

Merely mentioning that there are several inverting processes that maintain relational invariance of an organism doesn't explain life fully. It is true that living systems maintain identity, but they exhibit irritability, reproduce, evolve, and even cognize. How does invertibility explain these apparently different phenomena of life? We will discuss these issues now.

11 Invertibility takes place by reproduction when IT interactions are thermodynamically irreversible.

Almost all schools of thought on biology consider metabolism, maintaining the balance, structure, growth and development, as fundamentally distinct from reproduction of the organisms. The theory of autocatalytic hypercycles proposed by Manfred Eigen and Peter Schuster propose that organisms consists of functionally related self-replicative units formed into multiple feedback loops (autocatalytic hypercycles) [9]. Stuart Kauffman and several of his colleagues at Santa Fe Institute extended this model to study various kind of self-organization encountered not only in living Beings but also in several corners of nature[13, 12]. The Santiago theory proposed by Maturana and Varela extend this view and propose that cellular metabolism consists of repairing itself from perturbations by self-production (autopoisis) [16]. Maturana defines autopoietic systems as follows:

> We maintain that there are systems that are defined as unities as networks of productions of components that (1) recursively, through their interaction, generate and realize the network that produces them; and (2) constitute, in the space in which they exist, the boundaries of this network as components that participate in the realization of the network. Such systems we have called autopoietic sys-

tems, and the organization that defines them as unities in the space of their components, the autopoietic organization.[37]

Autopoietic systems are also organizationally closed, i.e., they have a circular network of interactions, rather than a tree of hierarchical processes.[31] Living systems are said to be in a continuous dialogue with Nature. The identity of living system 'emerges' in this dialogue *with* the environment. To quote Varela:

> In the face of interactions that perturb it, a system-whole asserts its individuality through compensations. But how is this stbility achieved? We know: through the mutual balance and regulation of the processes that constitute it ... It is the closeness in organization that ensures stability; organizational closure represents a universal mechanism for stabilization.

Stability, thus, can be meaningfully talked about only in relation to the surrounding environment. They also believe that the structure of the living systems is the relations between the physical components. While living systems are organizationally closed, but they are open interms of matter and energy. It is the characteristic of living systems to coninuously produce itself (self-production), but by keeping the relative order of the components more or less intact. Maturana and Varela's viewpoint is quite in line with the model presented here. Let us extend this view of self-production to understand how metabolism and reproduction intimately related.

According to the current model reproduction is one of the main mechanisms by which invertibility is achieved maintaining the identity of the organism. Consider a system in an environment. The system, let us suppose has several components (metabolites) and their functional network of relations among themselves constitutes the living system. Every component in this network of relations has an important role to play, and absence of any one of the components disturbs the organization of the system. Let us now assume that one of the components C get perturbed by some IT interaction in such a way that the component transforms into C'. Since C is one of the core components of the system and has an important role to play, it must be restored. But thermodynamic conditions existing may not make the conversion of C' into C possible, because most often it is an uphill reaction. If this reversibility is not possible, the system may disintegrate.

Under these conditions there exist only two possibilities. One is to replace C with another instance of it from the surrounding environment. This way the system can restore C if there is enough supply of C in the environment. The second possibility is to *make* another copy (by reproduction or replacement) of C within the system. Sometimes if there are several copies of C available in the system, another C could take its role. But even in this case, the depleted C must be restored. The restoration process is a biosynthetic process of C, a pathway by which C gets produced from other substances available within the system. This is where the system must spend energy (to do work) for restoring the metabolites transformed by IT interactions, if they are not available from the environment or food.

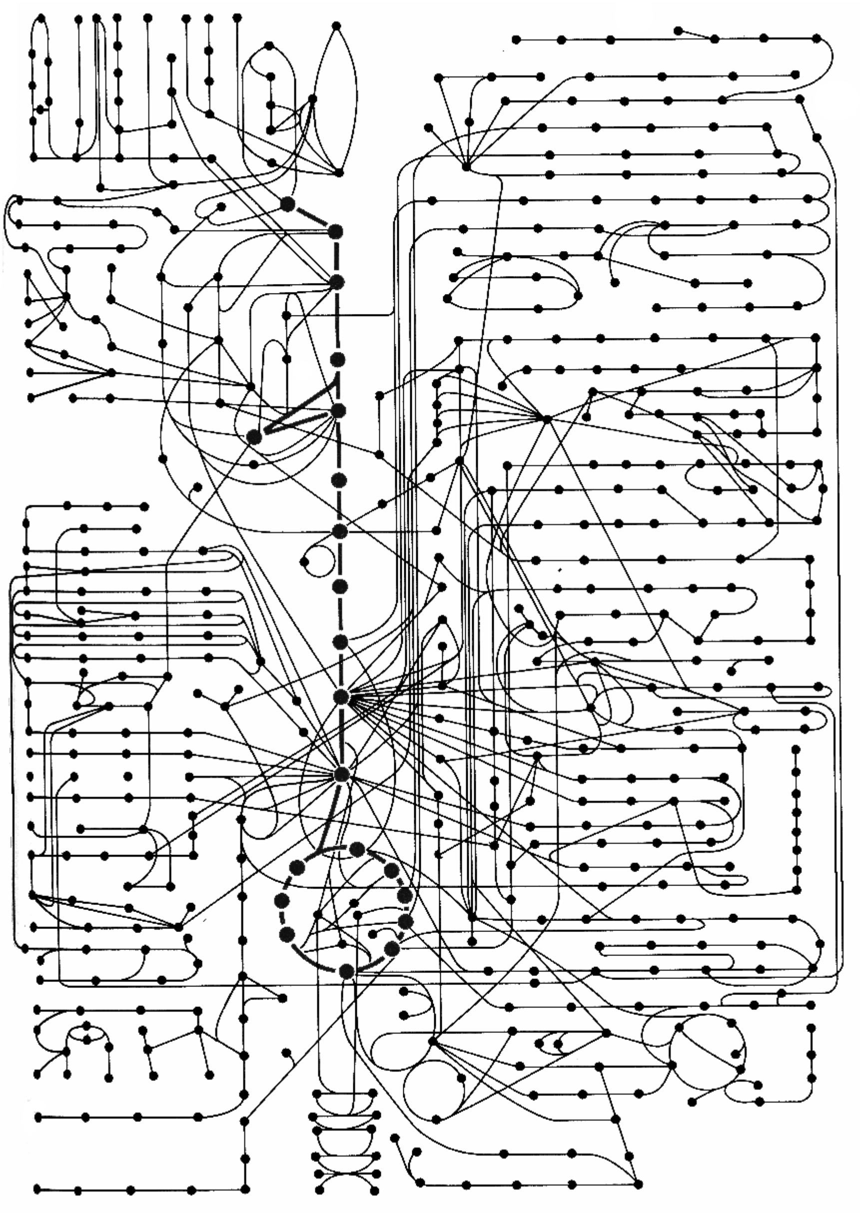

Figure 4: A diagram showing the map of various metabolites, represented by nodes in the picture, and the links, representing the enzymatic reaction, between them in a typical cell. Diagram from *Molecular Biology of the Cell* by Bruce Alberts et.al.[1]

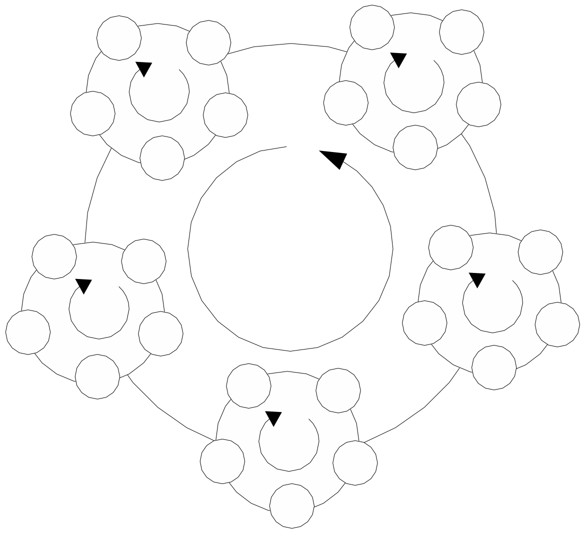

Figure 5: Metabolism is reproduction of dialogically invertible macromolecules (proteins, RNA, and DNA), which in turn catalyze the reproduction of other metabolites in a cyclic manner. Each circle in the figure represents a cyclic metabolic pathway reproducing a metabolite of another cyclic metabolic pathway, and so on. The number of nodes in each cycle may vary. This is a modified representation of autocatalytic hypercycles proposed by Manfred Eigen and Peter Schuster[9].

If the system has a chemical pathway to *re-produce* C using other substances (usually called precursors) then that system is in a state of invertibility with respect to C. This pathway is catalyzed within the living systems by enzymes, which are polypeptides (proteins), made in turn of amino acids. Though each enzyme can participate in several reactions, since it *inverts* back to its identity after the reaction, they too get perturbed and soon disintegrate. Often disintegration is essential for that is the only way how energy is available for the cell under conditions when external feed is absent or less.

The enzymes required for this pathway are also to be *re-produced* by another pathway called protein synthesis (translation) with the information decoded from an mRNA molecule (a polynucleotide) with the help of another protein-rRNA complex called ribosome. There are also other pathways that produce amino-acids that are required for protein synthesis. Amino acid producing pathways also need enzymes. Ribosomes are also to be reproduced. Each mRNA molecule can produce several copies of a protein, but they too disintegrate, and are required to be replaced by transcription (process of producing mRNA from DNA). All these re-productions need a lot of energy, and the system obtains them by catabolism (disintegration) often by recycling the larger biomolecules within the cell. Re-production and catabolism are the two inversely networked processes maintaining the organizational closure of the system.

Most metabolic cycles in a living cell are controlled by special enzymes called allosteric enzymes occupying a crucial node of the cycle they control. Just as enzymes function due to weaker interactions within the molecule, a group of proteins get together to produce very large complex proteins with several polypeptide subunits. Even the interactions between these subunits is by weaker bonds. These complex molecules display the property of having several active/regulatory sites (multiple interfaces) on their surface. One of the subunits of this complex when interacts with a substrate or a modulator, not only the subunit undergoes conformational change, it gets transmitted almost instantaneously to other subunits in the complex, making another subunit of the complex to perform an action, usually this is performed by inhibition or amplification of the metabolic pathway. Thus the control of metabolic reactions also happens by invertible dialogical interactions. Most pathways in the cells are multi-enzyme systems. In some of them the end product of the pathway inhibits the progress: a negative feedback loop.

Every small perturbation the system undergoes with the environment requires a long chain of production cycles. All the metabolic events that are taking place in a living cell, according to the current view, is a repairing process by reproduction carried out by molecules undergoing invertible dialogical interactions. Normally biologists use the term 'reproduction' only for the replication process of DNA or cell division or birth of an organism, but not for the proteins and other building blocks of the various macromolecules the cell is made of. I suggest that this typical distinction between reproductive components (*genotype*) and the structural and physiological components (*phenotype*) though is apparently justified, it masks the fact that all the biomolecules are reproduced by biosynthetic pathways. It is not possible to chemically distinguish production process from reproduction. The term 'self-replication' is misleading if it is attributed only to genotype and not to phenotype. The view that self-replication as a distinct feature of only genotype (DNA) deserves some discussion.

All the reproductive cycles form a network within protoplasm (the buffering environment of water and other amphoteric and amphipathic substances). This entire network terminates with one reproductive cycle of a macromolecule, namely, DNA, whose re-production (replication) happens along with a partition of the network of other reproductive cycles. In this interpretation DNA, with two long complementary polynucleotide chains held again by the weaker invertible hydrogen bonds, is a symbolic information rich identity reproducing mostly once during each cell cycle (cell division). This is one of major difference between other macromolecules which are reproduced several times during the G-phase (growth phase) of the cell cycle and DNA which reproduces just before cell division during S-phase. The most important difference between DNA and other metabolites is that the sequence of DNA is more or less conserved and it is usually identical to the template.

There is another way to look at the picture. Consider DNA as a complex molecule present in the cell, which when perturbed by the environment (including cellular environment) manages to repair with the help of repairing enzymes.

This repair process requires the basic resources like nucleotides and energy, which in turn are to be produced by the cellular metabolic network, and several of the enzymes required for this process too are to be copied starting from the central DNA itself. Thus there is a network of reproducing cycles all culminating at DNA. DNA seems to be the terminal node of the cellular metabolic cycles. DNA also seems to have the longest life of all the biomolecules in the cell, actually equal to the life of the cell itself. This indicates that DNA is nothing but *the molecule at the turning point of the cell cycle*. Thus DNA is clearly one of the core wheels, but not the only core wheel (see Figure 7).

Let us connect this scheme to the assertion that invertibility is the logic of life. In an environment where IP and IT interactions happen any Being can persist in only one way: by reproduction. Each instance (individual) of Being cannot remain forever, but a copy of itself can only continue. So there exists only one way of maintaining identity, since repair is not possible beyond a limit. Metabolism (replication of DNA included) is a mechanism of repairing perturbations caused by the environment[13]. Also it seems that the best possible way to eliminate continued perturbations in the environment is to capture and control the perturbing agents of the environment within the system to the extent possible by converting them to other compounds and recycling whenever needed. Several of the biopolymers are used to store energy, which can be used for performing work—a way of capturing and arresting the perturbing agents.

Imagine a situation where the system doesn't have such invertible mechanisms within itself. All the replenishment must come from out of the system. Such systems require enormous amount of feed of energy and matter and they can not sustain a moment without external supply. Artificially made machines are mostly of this kind since they are linear and do not generaly form loops within. This is the difference between *autonomous systems* and artificial machines. Artificially made control systems also indicate that wherever control or some element of autonomy are achieved they are due to *feedback loops* in the machine.[14] A large number of chemical reactions take place within the cell at such low energy levels is entirely attributable to the dialogical invertible interactions of the enzymes and the buffering protoplasm on one hand, and recycling nature of the metabolic pathways where the cyclic network compensates the constant external energy requirements by feedback loops on the other. This sort of organization not only saves energy and matter, but makes the systems relatively autonomous. In the current model all autonomy is held to be relative. Autonomy is a function of invertibility (an internal means of replenishment) and it also reflects the degree of dependence on the external environment.

Another important consequence regarding the nature of enzymes deserves to be noted here. According to the received view enzymes catalyze the biochemical reactions, where we trace the path of reactants and products. Say, for example, when we talk of Krebs cycle—the hub of cellular pathways—we say

[13]The connection between metabolism and repair are also worked out by Robert Rosen, a theoretical biologist. Though my knowledge of his work is limited, it is important to mention here that this thinking is not new.(See [26].)

[14]This is the central claim of cybernetics (See [34],[2])

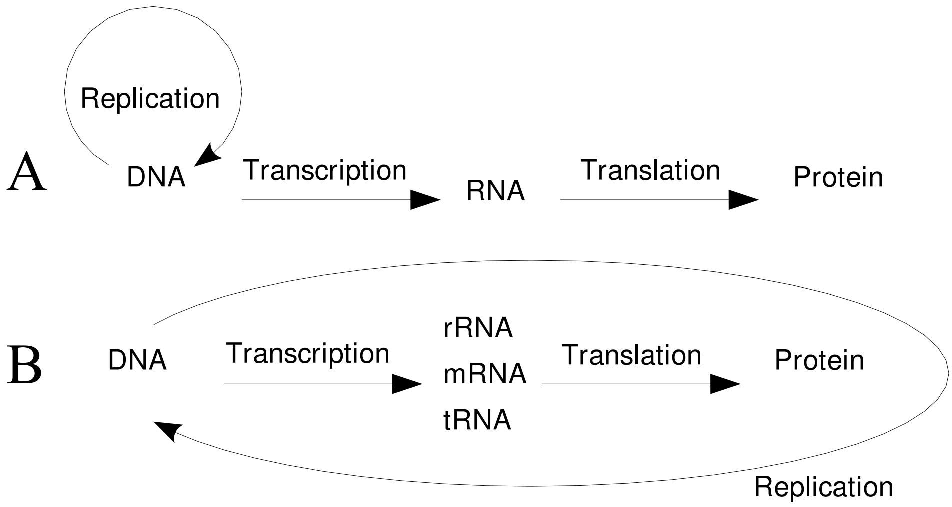

Figure 6: Comparison of the received central dogma (A) of molecular biology with its appropriate representation (B).

that oxaloacetate and Acetyl Co-A participate in a reaction catalyzed by the enzyme citrate synthase to produce the product citrate, and then citrate succinate etc. We trace normally the path of the substrates and products making enzymes mere catalyzers. I think it is more appropriate to look at the metabolic pathways as an organization of functionally linked enzymes, and other enzymes reproducing them in turn, nullifying the perturbations caused by the environment maintaining and propagating the identity of the cell. Keeping the dialogically invertible molecules at the center stage, we get a different picture of 'the central dogma' of molecular biology.

In this modified picture we have dialogically invertible amphipathic, and amphoteric biomolecules (phospholipids, proteins, RNA) at the center, connecting and controlling the interactions of three kinds of molecules: At the first node we have inorganic perturbing agents like energy, water, oxygen, carbon dioxide, nitrates and other minerals which are captured and controlled to produce the second node of the network consisting of a big stack of macromolecules like carbohydrates, lipids, and some proteins. The third node is the information rich representation in the form of DNA. These three nodes constitute the three terminals of metabolic interactions of a living system. In a highly abstract sense these three nodes actually represent the three main manifestations of reality, energy, matter and information, where the first two are substantive in the sense they are conserved, while the last is symbolic and non-substantive, hence not conserved making it copyable.

According to the standard central dogma of molecular biology, proposed originally by Francis Crick and adopted generally by almost all the biologists

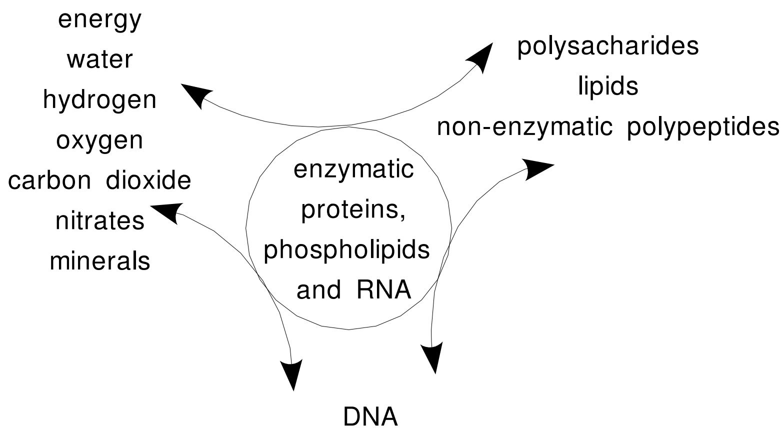

Figure 7: Alternative Central 'Dogma' of Molecular Biology: An ideal cellular metabolic network seemingly terminates at three nodes: 1. the energetic inorganic simpler molecules on the left, 2. the energy storing complex polymers on the right and 3. the information storing polymer DNA (deoxyribo nucleic acid). At the center are the dialogically invertible macromolecules (phospholipids, enzymes and ribonucleic acids (RNA)) with multiple sites of interaction controlling the all interactions in the cell.

today, the information flows only one direction as shown in the figure 6(A). DNA *self-replicates* producing another copy of itself, and transcribes to produce RNAs of various kinds (rRNA, mRNA and tRNA), and RNA in turn produces proteins by a process known as translation. Main point of course of this dogma is that information doesn't flow backwards, that is from proteins → RNA → DNA.

The most objectionable point of this model, I think, is the replication of DNA. Replication of DNA is a very involved process. Let us briefly trace what all happens: DNA replication requires enough number of nucleotide-triphosphates in sufficient number. Though this amount is mathematically twice the amount of nucleotides present in any given copy of DNA, but since this process is a chemical process the number has to be several times more than twice the amount. Producing these resources assumes that the cell must carry on the process of generating these in enough number. Each nucleotide contains ribose sugar and nitrogenous bases. They need to be supplied either from food or produced internally by the cell. Either way lot of biochemical pathways happen under the regulation of enzymes. Thus producing all the enzymes means, transcription and translation of them. The polymerization reaction is catalyzed by polymerase enzyme, which is a protein. Transcription and translation also need other enzymes and ribosomal constituents. Several of these reactions in a living cell cannot take place without the role played by several other metabolites and macromolecules and other organelles. Thus the whole cell should initially *re-produce* by autopoisis so that all the resources necessary for one *single* replication of DNA are available. Just a DNA replication–the minimal work expected from a cell without doing any other special function—most of the cellular machinery is already in use. The facts are drawn from what we know about the molecular biology of the cell. Isn't this a misrepresentation to say that DNA replicates on its own? Several other criticisms of gene centric biologists did point out a milder part of this problem—without proteins DNA cannot replicate. But my point is not only regarding proteins, almost everything else inlcuding the membranes, minerals . . ., the entire cell must operate to replicate DNA. Artificial replication of DNA in test-tubes is a case where all the resources are provided by us. And those resources were mostly taken from extracts of living tissues.

What then should be the correct representation? I think, instead of calling DNA self-replicating we could properly describe that the cell as a whole is self-replicating. Since each cell cycle corresponds to one replication cycle of DNA, it is appropriate to interpret that DNA replication is at the terminal node of all the metabolic loops.

It is true that the information for the new daughter strands of DNA is already contained in the parent strands. But creating all the necessary conditions for replication to happen within the cell requires the entire cell cycle to operate. If replication of a cell is almost equivalent to working out almost the entire cell cycle, wherein everything else is also replicating (as elaborated above), then what is "self" about "self-replication"? "Self-replication" is one of the most misleading expressions of modern biology, taught as a golden principle to all school children propagating a misconception.

Before we move to the next section, let me point out that the most vital components of the living system are the dialogically invertible components of the cell, phospholipids, proteins, and RNA. They constitute the *semantic zone* of the cell, where the system interacts with the the external world, assimilates some of the perturbing agents by taming them and constructing 'piles' of metabolites (biopolymers), and makes the self-representing DNA.

How DNA began to represent the structure of RNS and in turn of proteins is the problem of origin of life. We cannot deal with this complex question here, but a few comments coherent with the rest of the story at this place are appropriate. Views on origin of life are divided into *metabolism-first* or *reproduction-first* approaches–corresponding to—protein-first or gene-first approaches respectively. Based on the proposed model, this 'chicken-egg' situation doesn't actually exist, since the central claim of the model is that metabolism *is* reproduction of the entire state of the cell including DNA. The genetic and somatic distinction has only conventional significance. I hypothesize that the early living systems must have embodied the some primitive kind of semantic zone consisting of dialogically inverting molecules like phospholipids, proteins, RNA. Of these RNA is a proper candidate for having the ability to represent proteins on one side and DNA on the other. Recently several researchers made this their working hypothesis to solve the problem of molecular evolution.[15] In this connection the arguments and analysis of Marcello Barbieri are revealing and are coherent with the proposed model. The logical analysis suggests that:

> A code, ..., requires three entities: two independent worlds and a codemaker which belongs to a third world (from a philosophical point of view this is equivalent to the triadic system proposed in semiotics by Charles Peirce). In the case of the genetic code, the codemaker is the ribonucleoprotein system of the cell, a system which operates as a true third party between genes and proteins.(p. 5,[3].)

He suggests that apart from genotype and phenotype, there exists a *ribotype*, the codemaker. I suggest that instead of distinguishing the two independent worlds as phenotype and genotype, we should divide the world as suggested in the figure 7. It is not justified to include all proteins as phenotype, since other biopolymers, enzymes as explained above can be distinguished based on whether they are dialogically invertible or not. I suggest all dialogically invertible stuff, not merely riboproteins be interpreted as ribotype. Apart from the two 'worlds' within the cell, ribotype should also have codable connections with the external world as shown in the figure. As argued by Barbieri, coding and decoding activities in the cell are not at all restricted to genes, many more extensive languages other than genetic code are at work in the cell. Space doesn't permit me to discuss this important issue initiated by Barbieri, whose views complements my current undertaking.

What about the reverse flow of information, which is precluded by the central dogma? If we take the logic that I am following, for every process there exists an inverse process, there must exist the reverse flow of information. I think the reverse flow of information is not apparent because it takes a detour, a very complex one at that. The minimal cell cycle just for the replication of DNA, as explained above, is precisely this *regress*. It is an open question to understand the precise mechanism of how information began to get stored in the form of DNA. This is one of the questions par excellence in the context of origin of life.

For every process we supposed that a counter process exists. But, often, every counter process doesn't exist within the Being. This makes the Beings dependent on other Beings. For example, the counter process for respiration doesn't exist in animals, but in plants, making the former depend on the latter. Plants however have both of them, so relatively more autonomous. But even plants depend on the counter process of nitrogen fixation either on bacteria or on the atmospehric processes. The model thus can be extended to ecology quite smoothely. It is prudent therefore to continue to look for the counter processes, some times as far as in the whole of Biosphere, to arrive at organizational clo-

[15] For a good review of the debate see for example, Marcello Barbieri's *Introduction to Semantic Biology*, where in he proposes ribotype theory on the origin of life[3].

sure and conservation.[16]

12 Adaptation, complexity, and autonomy are various manifestations of invertibility.

How do we understand the complexity of a system? Let us recall that a system is defined as a composition of included contraries. Consequently a complex system is a composition of many *kinds* of process-anti-process-pairs. Beings' ability to survive in a specific environmental condition depends on the availability of an invertible work cycle for each kind of perturbation. A system is said to be *adapted* to an environment if the perturbations are compensated by the system. For example, an organism that can withstand a given kind of perturbation, e.g., a range of temperature, is adapted to that environment due to a work cycle that can repair the damage caused. But since environment has other kinds of perturbations, like chemical, osmotic, etc., it is possible that a system is adapted heat wise but not osmotically, hence as a whole the system may not survive. Different systems could have different range of tolerance for each kind of perturbation. Any given system's adaptation to a given environment is possible only if all the forms of perturbations are tolerated by the system.

Complexity of a system can be measured in two steps, corresponding to first order and second order complexity. The first order of complexity of a system is related to the tolerability of *kinds* of perturbations. The number of kinds of perturbations—each process-anti-process pairs—in a given environment are constant. Therefore almost all organisms that are adapted to that environment share more or less smilar first order complexity.

The second order of complexity is to do with the range of perturbations tolerated by the system, keeping the kind of perturbation constant. Most variations among different species of living organisms is with regard to the second order of complexity. All cells live in aquatic condition so every organism gets one score for their ability to counter osmotic perturbations. But organisms differ in their ability to counter the *range* of osmotic perturbations—ability to survive in wide range of solute profiles. The second order of complexity is a measure of how many possible profiles of solutes an organism can withstand. Similarly all organisms that can resist say virus infection get one score of first order complexity, but organisms differ in their immunity profile: the number of antibodies an organism produces. This way, I think, we can generate a complexity index as a product of the first and second order complexities. Greater the second order complexity, *wider* is its ability to invert the perturbations of a given kind. It may be possible to find additional dimensions of complexity.

This model of complexity is not based on the hierarchical order: simple

[16]This thought essentially is an extension of a general belief in conservation principles. The relation between conservation principles, symmetry and scientific creativity are proposed to be based on this inverse reason. Cf.[18]. Emmy Noether's proof, that every conservation theorem is a symmetry principle, is in this regard very interesting.

molecules→ complex molecules→ cells→ tissues→ organs→ organ systems→ organism→ population→ community etc. Hierarchical order is based on structural order of complexity, while the proposed characterisation of complexity is based on the physiological complexity.

Animals, particularly, have an additional ability to move from place to place. This is an ability accountable to the organisms' resistance to mechanical perturbations. Some plants cannot grow against gravity, and some animals do not move. Animals' ability to withstand mechanical perturbations is not due to inertia (mass) but due to their ability to apply counteracting force by doing work.

A telling example to understand different orders of complexity is our own body. Human body is highly complex with respect to the number of invertible (controllable) joints the body has. While most mammals have roughly the same number of joints, their ability to control them is limited. In this respect human body scores the highest, particularly the fore-limb (hands). There is, I hypothesize, a positive correlation to the number of controllable joints and the size of the brain. It is known that most of the human brain size is actually accountable to controlling the movement of different joints. Also notable is the degrees of freedom enjoyed by the different joints. This is the reason why, when computing the index of complexity both the first order and second order must be taken into account. Added to biological complexity, human beings' behavioral complexity—additiona order of complexity—by their ability to use tools, extends their ability to resist environmental perturbations many times beyond any other Being.

Though it is often stated that human beings are more complex than other beings, no criteria were available. Based on the proposal of computing an index of complexity, I think, it is possible to explain why human performance is several orders higher than other Beings. It is in order therefore, to suppose that *greater the complexity index greater the adaptive ability*. Though all these claims need better empirical substantiation, on the face of it, it seems like a good working hypothesis.

The conditions that make autonomy, control and information processing possible are very similar. Stuart Kauffman gives the following answer to autonomy, a condition for acting on its own behalf.

> An autonomous agent must be an autocatalytic system able to reproduce and able to perform one or more thermodynamic work cycles (p.49 [13].)

This is a minimal condition for autonomy, though not sufficient. It is in principle possible to build a machine meeting the above condition. But can we say that the machine is autonomous? Tightly held work cycles operating in a mechanical way, I think, cannot make autonomy possible. Tightness must loosen. There should be some scope for freedom and choice within the scope of constraints. Mechanically following a goal also cannot be construed as purposive behavior.

Recalling the role of loose interactions (dialogical) in defining the logical space of life, I propose that the system must perform thermodynamic work cycles *dialogically* and with *deliberation*, accommodating freedom and choice. Under what conditions can a system transit from relative autonomy (Kauffman kind) to real autonomy.

Let us take the case of a photosynthetic plant, which is sensitive (gets perturbed) to a specific range of sun light. Plants have no choice. To repair the perturbation it must nullify it, and it ends up capturing the energy in chemical bonds of starch.[17] Please do note that most of the starch that plants make is not used by the plants in their work cycles, and it accumulates beyond necessity. Thanks to their helplessness! We survive due to their misery. Consider a Being that depends on plant for the basic nutrients, but have no sensitive chlorophyll to make loads of starch. They hide in the shade of plants to make a living. The point is: by oxidizing what plants have in plenty, animals liberated themselves from performing the reducing role. Animals are more to the right side of figure 3. What did they achieve from this? They remained more *plastic* and less heavy since no need to carry loads of unnecessary biopolymers. They wandered around and got exposed to newer perturbations and which were not available to plants, and repairing them makes animals physiologically more complex as defined above. Therefore merely performing more and more thermodynamic work cycles doesn't ensure the kind of autonomy we want to account for—i.e., to act on its own behalf.

Consider a long biomolecule folding and unfolding, wiggling and squirming, going left and right, by breaking and forming weaker bonds. Energy for these is available in abundance in the environment where it is located, for if a bond is formed at one place, it is broken at another place. In this kind of *loose* world there is some possibility of freedom and deliberation. The molecule can try some of the invertible interactions and since its identity is not lost, what it does is seemingly for its own sake. This seems to be the only possible physical space where autonomic behavior is possible. Earlier we saw that living state is also possible in this very space. This is to say that several of the different manifestations are all emerging from this dialogically invertible state.

13 Dialogical invertibility is also the basis of cognition.

Any discourse on cognizing systems (complex systems that are capable of cognition) must address a peculiar problem of identity. The problem can be stated as follows: In order that a cognizing system perceive an object, there must be a *recognizable ontological change* (transformation) in the system. Let us call the

[17]Normally we consider plants as autotrophs capable of making their own food, but actually their food is light, water, minerals and carbon dioxide. Therefore calling them autotrophic is misleading, but then instead of throwing the baby with the bath water, it is appropriate to say that they are relatively more autotrophic than other Beings and they are less dependent on other Beings. Biologists need to throw several other dichotomies and enter the domain of relativity where we talk in terms of degrees of difference instead of categories.

ontological change a *difference*. It is also necessary that the difference be different from other perceptions (differences). Therefore the system should also be capable of differentiating the differences. Let us tentatively define knowledge as *differentiated difference*. This definition of knowledge also follows from the supposition that to say what something *is* we should also say, though not explicitly, what that something *is not*. Thus the very idea of knowledge presupposes meta-level differentiation of difference.

On the other hand, in order that the knowledge be *decidable*, it is necessary that the differentiated difference remains identical (invariant) over time. It doesn't mean that our knowledge of any object should remain unchanged. It means however that the belief that we hold about a certain object for a given period of time must be fixed in order that our beliefs be epistemically decidable. Thus on the one hand every epistemically decidable piece of knowledge must be an identity of some sort, and on the other hand in order to generate a differentiated difference the cognizing system at an ontological level must transform itself. It seems therefore necessary that a cognizing system must change in order to perceive and also at the same time hold on to certain identities in order to believe. (We presuppose that perceiving and believing are the most basic operations of every cognizing system). How can the system change itself and at the same time maintain a set of identities?

Since the level at which the transformations occur being different from the level at which identities are asserted, the problem about the ontological Becoming and epistemological Being can be resolved. The transformations taking place during perceptions are *substantial* and ontological, while the generated identities (beliefs) are *formal* and epistemological. Therefore it is possible for a changing system to hold unchanging beliefs.

If we recall, a similar problem was encounted while discussing the possibility of a Being in an actual world of interactions. These two problems are actually two different manifestations of the same. So the way we try to reconcile this is by drawing a distinction between ontological Becoming and epistemological Being. The discussion below will elaborate on how to distinguish between the two. We shall use this category of Becoming-Being, as introduced in the earlier sections, to bring home two of the main points of the paper that cognition is nothing but an adaptive behavior common to all living beings, and that living and knowledge are ontologically identical.

The nature of our position can be clarified by contrasting it with the traditional Platonic division of universals and particulars into Being and Becoming respectively. For Plato there exists in this unreal mundane world only particulars which constantly change, while in that real heavenly world of Forms only universals exist, which by definition do not change. He allowed only one relation between universals and particulars, which when stated in the modern language reads as: Universals are types and particulars are tokens. However he allowed genus-species relation between universals. Based on this relation he showed how hierarchic arrangement of different universals is possible, distinguishing some of them as more simple than the others [18]. Scientific knowledge (*episteme*), according to him is possible only of the unchanging Beings (universals).

He therefore precluded the possibility of a science of motion, which also means no application of mathematical knowledge to the science of motion. He influenced even Aristotle on this point, who otherwise departed from him on many fundamental points. His influential position is partly responsible for the belated start of a mathematical study of motion till the time of Galileo.

While Plato, following Parmenides, 'successfully' separated Being from non-Being, Heraclitus' struggled to find a plausible ontological system that could inhere the opposites in it. Platonic position has been practically rejected by Galileo, who showed how mathematics can be applied to the study of motion.[18] Since the Platonic identities are identifiable with Being, they can be employed to describe only unchanging essences, if any, in the reality. The history of natural sciences, however, contains evidence to this fact that most scientific knowledge has been about *Becoming-Beings*, or invariant relations obtainable between certain variable parameters. In fact most significant applications of mathematics in natural sciences has been to study changing phenomena (Becoming) rather than unchanging phenomena (Being). This has become possible ever since we realized that though mathematics cannot be applied to change per se, but it can be applied to the patterns of change. In other words, *invariance of variance* is mathematically shown to be amenable. This realization is in itself a major transition in the evolution of knowledge systems[18].

These remarks become all the more relevant for the appraisal of a science of complexity, and therefore to the current undertaking, because, complex systems are dynamic and at the same time exhibit remarkable stability and control. The current developments in the non-linear dynamics and mathematical models of self-organization have demonstrated that the Being that emerges from the ever Becoming complex systems can be described mathematically.[19] Classically it was thought that simplicity makes mathematics possible. However the fact of the matter is that it is to tame complexity that mathematics can be best employed. Thompson argues that though biological systems are complex, they can be 'tamed' only by the use of mathematical descriptions of the dynamics of the systems.[29]

From the above observations it is possible to articulate the possibility of knowing in an ever changing internal as well as external world.

A rich environment can introduce different kinds of perturbations in a system. Any system adapted in that environment requires corresponding inverting processes distinguishable again by the interactional coupling between the perturbing agent and the system. Having supposed that knowledge can be defined as a *differentiated difference*, the *genesis of difference*, as a significant piece of information, can be said to be the difference in the needed inverting mechanism.

[18] I had shown how Galileo, who followed the methodological guidelines of Archimedes, discovered a solution to the problem of characterizing the invariant properties of motion by applying *inverse reason*. A detailed case-study of how Galileo solved the problem of motion (Becoming) by applying inverse reason has been presented elsewhere (in Chapter 8 [18]).

[19] Ilya Prigogine, Manfred Eigen, Norbert Wiener, Von Neumann, McCulluch, Humberto Maturana, Francisco Varela, René Thom, Stuart Kauffman, Marcello Barbieri are some of the leading researchers who developed or applied mathematical models for complex systems. This list is not exhaustive.

This gives sufficient ground for symbolic or informational processing where the tree of knowledge can take its root. Thus Maturana observes:

> The fundamental cognitive operation that an observer performs is the operation of distinction. By means of this operation the observer specifies a unity as an entity distinct from a background, and a background as the domain in which an entity is distinguished [37].

Ontologically speaking there seems to be no other processes that take place for making cognition possible apart from the same dialogically inverting mechanism that enables a system to adapt and live in an environment. A telling instance from neurophysiology corroborates that information processing also involves invertible mechanisms. For example, the polarized (normal) state of neurolemma gets de-polarized (de-normalized) upon stimulation, followed by a re-polarization (re-normalization) process. It is during these inverse processes of de-polarization and re-polarization a *difference* is generated. This difference is variously called as 'spike', 'action potential' 'impulse' etc. Since the 'quantum' or 'quality' of inverting process depends on perturbing factors, whether internal or external, there is sufficient reason to believe that nothing more is essential for accounting the genesis of a code (information) about the external world.

From what we know about the sense organs, say photo-receptors like retina, it becomes very clear that inverting mechanisms are the basis of perceptual apparatus. When a ray of light falls on a sensitive retina, which is in an active normalized state, it gets perturbed. The perturbation must be immediately repaired, and this happens by a cyclic metabolic pathway of inter-conversions and the sense organ regains the normal state by inverting activity. If repair is not possible, which may happen if the intensity of perturbation is very high, the sense organs gets permanently damaged. This therefore sets a range of perturbations each sense organ can tolerate. Ultra-violet radiation or other extreme radiation on either side of the visible spectrum causes permanent damage. Thus the visible range is directly determined by the invertibility of the sense organ. Differences among the visible range can be attributed to either the 'cost' of repair or the kind of repair involved. Since the difference in inverting process is the actual source of information, the account given is consistent with Maturana's observations that:

> Perception . . . must be studied from the inside rather than the outside—looking at the properties of the nervous system as a generator of phenomena, rather than as a filter on the mapping of reality. . . . The focus should be on the interactions within the system as a whole, not on the structure of the perturbations. The perturbations do not determine what happens in the nervous system, but merely trigger changes of state. It is the structure of the perturbed system that determines, or better, *specifies* what a structural configurations of the medium can perturb it[35].

Based on what we said above it is possible now to specify what is a perceptual object that a subject may perceive. A perceptual object is that which can cause a perturbation in a cognizing system if and only if the system has an ability to invert the perturbations induced by it. Thus a close relationship between living mechanism and cognitive mechanism is suggested. The fundamental questions related to life and cognition are not independent of each other, and the same logical space which enables life also enables knowledge. These are two different manifestations of the same ontological phenomena.

We have seen in the earlier section, how a very large macromolecule with multiple sites of interaction can perform life-like activities. It is interesting to see that such a nature of the molecules which can have the option to work with several sites could be the kind of things that can cognize, since their identity is not transformed while actively working with the environment. Such a molecule is a necessary condition for some thing that can choose out of the available options. Since working out each of the options are invertible, it is ideal to suppose that such molecules can indeed be the best physical basis for "persistently increase the diversity of what can happen next." This character according to Stuart Kauffman is essential feature of autonomous agents.[13] In fact when we take cell as a whole to operate in its environment, on the surface of the cell there are numerous possible sites of action. When we have a population of Co-evolving autonomous agents, we get a profusion of diversity despite the sameness of all agents.

Perception, even if we suppose we have answered doesn't complete the picture of cognitive domain. For example every work cycle (a compensatory path repairing a perturbation) in the cell is not part of the field of awareness or perception. Cognitive agents can also opt or opt out certain perceptions? So what determines perceptibility? One needs to account for a situation where a system is aware that it is aware (consciousness). How to account for Pavlovian conditioning? What about theoretical knowledge and technical knowledge? And going beyond what is biologically endowed, using tools etc? Each of these questions pertaining to knowledge deserve more space, and cannot be dealt here satisfactorily. I will point out the possible ways of approaching to understand and solve these problems.

Only variations in the pattern of perturbations can be part of perceptual space. Many of the work cycles that take place in the body are not accessible, for they act in a recurring pattern, and becomes part of the rhythm of the body. Beings cannot notice patterns through perception. Only differences can be noticed. This is the reason why inductive knowledge, which captures only the differentiated difference, cannot read the underlying order of the world, for it is based entirely on experience. Heart beat can be noticed only when the there is a change in the rhythm. This applies to several other body rhythms. While some of them can be perceived when ever there is change in their frequency, some highly and deeply embedded order in nature can be approached only through theoretical knowledge, i.e. by model building and sophisticated experimentation.

The problem of controlling what should be perceived and what shouldn't be is like not getting into places that are known to be hostile. Autonomy of the agents is an important factor in such situations. This situation also presupposes some knowledge of the place. This is not a situation where the Being is repairing a perturbation only when it affects, it can foresee a place that causes irreparable damages. It may look as though connection between metabolism and knowledge domain begins to break here. This is indeed one of the limitations of the approach taken by autopoiesis, for it fails to distinguish between explicit-conscious and implicit-unconscious knowledge. Despite the limiation the theory explains the biological roots of knowledge. E.g. primitive life-forms like plants may have functional knowledge of their environment, and no form of explicit knowledge. They also have no ability to choose their environment based on previous experience. So their knowledge can be at best rated zeroth degree.

Further steps in the development of cognitive abilities from the given biological base become complicated. I have elaborated this process, extending similar logic, in other essays, and therefore will point the reader to these works here (See [22, 21, 20]).

14 Evolution of complex systems happens by increase in Beings' ability to invert the IP and IT interactions.

Evolution of new species according to Charles Darwin is by accumulation of useful variations that were naturally selected. When we ask the question which variations are useful, we were told, those which are naturally selected. There is unavoidable circularity in Darwin's model. Second, it is known to be a tautology: since it is devoid of empirical content—an unfalsifiable proposition.[20] But several circular explanatory models are often found in natural sciences. For most working biologists the principle of natural selection is the single most unifying idea of biology. It is one thing to say that the idea of evolution explains a number of phenomena in biology, but another thing to say that the theory of natural selection explains evolution. I think, most of these explanations appeal to us due to the concept of adaptation. Since adaptation is defined only in relation to the environment around, it looks as though there is something else other than adaptation operating. I fail to resolve any operational difference between adaptation and natural selection. We need only one of these concepts. Also Darwin's model fails to explain why some variations are better than others. I think this question cannot be answered without invoking a concept of complexity. Darwin's model abhors the idea of complexity like Aristotle abhors any role for mathematics in science. Following Darwin's model it is difficult to say

[20]Studies on self-organization have shown that order can arise without natural selection. There are several critiques of Darwin's theory. Most vociferous was by Lima-de-Faria in his provocative work, *Evolution without Selection.* Stuart Kauffman accepts it only partially, and he thinks strongly that physico-chemical models of self-organization complemented by natural selection can explain the phenomena of evolution. He proposes a few candidate laws in his latest work *Investigations*. We have no space to discuss them here.

that evolution is towards greater and greater complexity. This is the soft belly of Darwin's model. Let us see how the corrent model handles evolution.

It is common to believe that evolution doesn't happen without variation. But life is difficult if there is variation, since it is proposed that organisms function is to repair mutations. How do we account then for the variations? There are two possibilities. One of them is due to a perturbation (mutation) that cannot be repaired, so gets transmitted by reproduction. The other could be due to imperfections in reproduction, i.e. inability to succeed in making exact copies all the time. Both kinds of variations are possible in the current model. Thus, the model not only can account the possibility of variations, but also which are heritable variations.

Heritable variations are not necessarily useful variations. Thus arises the issue - which variations lead to survival of the fittest. Here the fittest Being is that which manages to withstand both IP and IT interactions, and adaptation is defined in relation to the environment. So there is an environmental selection. But the circular explanation is broken, by invoking complexity, since we have a physical basis for explaining how a given variation is useful over the other on the basis of invertibility. In a competing community of Beings, where different Beings interact with the nature, those organisms which manage to withstand more perturbations will survive better than the others.

Darwin's model also has other problems. The idea that all organisms descended from a common ancestor is a physical possibility, but not a necessary one. From the point of view of physical conditions, it doesn't seem necessary to preclude multiplicity of ancestors leading to different branches, or even allowing associations between different ancestors, as in the case of symbiotic association of plastids and mitochondria with other cells. So there is also a possibility of *converging trends* in evolution of complexity, not necessarily by gradual modification and descent. Increase in complexity is possible more by associations, compositions, superpositions, than by heritable variations. The formation of complex multi-cellular organization (morphogenesis) suggests that initially there is a phenomena of generating multiplicity, followed by differentiation of cells to introduce specialized tissues, then coordination of these specialized cells organized according to the principle of included contraries (antagonistic processes) bringing back the organizational closure required to work as an individual. Thus growth in complexity is not only about diversification and differentiation, but also integration and coordination. What Darwin's theory of evolution misses is precisely this aspect of integration and coordination. Self-organization models can explain this more satisfactorily.

One may say that this is taken care by natural selection. But what we need to understand is the mechanism of natural selection. Each being also has a 'volume' of nature within them, nature is not entirely in the environment and therefore external. Any theory of evolution of complexity therefore needs to account for the nature *within* and increase in its complexity over time. I have tried to explain how this happens by accommodating the contrary processes within the Being, increasing its complexity. I have also tried to explain how an index of complexity could be computed so that all Beings can be placed on a ndimensional scale. Since complexity and adaptability have a direct correlation, this in concrete terms becomes the empirical content of our model. Greater the complexity greater should be the adaptability. Is this mechanism of evolution falsifiable (a test for empirical content)?

A falsifiable condition of this theory is when one finds a simpler Being which is simple but exhibits adaptability in various adverse conditions. Another way to specify the falsifiability criterion is when two Beings, one of them complex and the other simple, both perform similarly keeping the environment constant. This is precluded by this model. Performance of a Being is a direct function of its complexity. Simple Beings cannot perform complex tasks.

In this model therefore, there is no separate mechanism for evolution. The very mechanism of dialogical invertibility, and increase of complexity by composing contrary processes is the principle of life as well as evolution. Evolution doesn't need any additional ontological presuppositions.

15 Conclusion

The way we approached the problem in this essay is by asking Kantian questions: What makes x possible? What are the conditions under which x is possible? What is the state of x? Approching this way the question I tried to answer in this essay is: *What are the conditions that make life and cognition possible.* The scientific revolution took place when we managed to make motion a state of the Being, as against, a property of it. This essay promotes that tradition. One of the characters of that tradition is to understand the relation between things, and not the thing-in-itself. The other important charector of that tradition is again not to study change-in-itself, but the pattern of change (invariance of variance). Galileo introduced this method. Newton, Leibniz, Einsten, Dirac . . . embellished it. Harvey's remarkable achievement was to discover and explain the conservation of blood, by introducing arguably for the first time the model of explaining life processes by proposing counteracting processes—by distribution and collection. Claude Bernard and Charles Sherrington discovered several such patterns and embellished the thought in biology. What is wrong with this science that life and congition continue to slip away.

Thus the challenge is: What is the phase space that makes a living being possible? Specifically this question amounts to finding out the conditions underwhich autonomy and control are possible and more work can be done with less energy. There exists, as argued here, a few possibilities of doing more work with less energy without violating the principles of thermodynamics. *Recycle. Reproduce. Repeat. Repair. Invert. Loop.* As a whole there is a plenty of recycling in the biosphere—the principle of ecology. But that will not make a Being gain control. What we need is: *recycle within the Being.* And this is self-re-production. The genesis of control or autonomy.

This essay argued for a modified foundation and an assimilationism, as against reductionism, for accounting complex phenomena like life, cognition and evolution. Based on the new foundations, the analysis indicated some counter intuitive implications like: chemical reactions can happen independent of heat under idealized conditions; all systems, including non-living, counteract perturbations to exist; non-living systems are more open than the living.

Though this is a theoretical exercise, it is claimed to be falsifiable. What are the conditions when this model is false? If we find an absolutely closed system that doesn't interact with others, if we find an object that exists independent of its environment, if cold-reactions are proved impossible, if we find autonomy without invertibility, if we find any molecule like DNA that replicates on its own in the absense of a cellular environment, if we find a sense organ or an artificial sensor that percieves without invertibility, if we find a complex life form independent of history, this model is false.

To sum up: In a world where there are abundant Becoming-Beings that are systems but not atoms, where they perturb each other, a world where systems in a very large number with heterogenous interfaces perturb each other, systems tend to distribute energy by dissipation (IP interactions)—first tendency. Different systems have different active areas by virtue of their structure. Just as systems inevitably distribute energy whenever there is contact, they are also inevitable to be part of IT interactions, whenever active areas (functional interfaces) come into contact—second tendency. Current science does not accept this second tendency—an asymmetry. All Beings are open, and their adaptation in an environment is an expression of their invertibility of the two tendencies. Living beings are part of a special dialogically invertible space made by amphipathic agents like water molecules on the one hand and agents with multiple interfaces like biomolecules with possibilities of interacting among their own functional interfaces on the other. This space makes possible for a dialogical opposition of the two tendencies: distribution and collection of energy. Thus, living being is described to be a neither-nor-state, between the two extremes. The characteristic of this space is to maintain the state by replacement, reproduction, recycling or feedback. The abundance of little loops produce highly efficient work cycles, minimizing external energy dependence. A self-re-producing network of such Beings manages to engulf a process and a counter process within the network of Being, to counteract the two 'deadly' tendencies. A Being capable of displaying behavioral changes without undergoing change in identity is born. And this logic continues to operate recursively to explain physiology, epigenesis, evolution and cognition. The same model is then applied to understand the nature of adaptation, complexity and autonomy.

The initial cognitive base of a living being is rooted in the invertibility of the perturbations from the environment. It is hypothesized that this repairing process itself becomes the difference, and the processes that are induced in turn within the system generate a differentiation of difference, which is defined as knowledge. However, this knowledge is implicit. The story thus far cannot account for conscious cognition, which is proposed elsewhere [20, 22, 21].

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