Towards a Model of Life and Cognition

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Contents

In this essay, I undertake to outline an alternative ontological foundation which makes biological and cognitive phenomena possible. The foundation is built by defining a model, which is presented in the form of a description of a hypothetical but a logically possible world with a defined ontological base.

Normally one would say what is wrong with the existing foundations of biology, and then say what can be the alternative. Instead, I will contrast the position I take with others and examine the consequences. This way I think readers will be able to see the context and understand how and why I am departing from the mainstream biological thought. This style of presentation is also convenient for the task at hand because I must preserve enough space for a complete and comprehensive outline of the model, instead of filling pages criticizing earlier models.

The term 'life' in the title is used to denote a collection of phenomena, but mainly physiology, reproduction, evolution and also the special aspects of life like complexity, adaptation, autonomy, purposive behavior, and self-organization. And the term 'cognition' is used to denote perception, thinking, consciousness, and abstract knowledge. Due to limitations of time and space, I will focus on perceptual aspect of cognition and the other higher modes of cognition mentioned above will be briefly alluded to, in order to make coherent connections with the model. On the whole, I will try to make it more or less self-contained.

Biology rests today on quite a few not so well connected foundations: molecular biology based on the genetic dogma; evolutionary biology based on neo-Darwinian model; 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. Can there be an underlying connecting theme or a model which could make these seemingly disparate domains interconnected? I shall atempt to answer this question.

By following the semantic view of scientific theories, I tend to believe that the models employed by the present physical sciences are not rich enough to capture biological (and some of the non-biological) systems. A richer theory that could capture biological reality could also capture physical and chemical phenomena as limiting cases, but not vice versa. During the course I will find affinities and relate my position with the innovative proposals made by Ilya Prigogine, Manfred Eigen, Humberto Maturana, Francisco Varela, Marcello Barbieri, Lima-de-Faria and Stuart Kauffman, 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.

This essay tries to throw light on several foundational questions. In anticipation of what is forthcoming in this essay I mention the following questions:

- What is the nature of Beings?
- What is the basis of interactions among Beings?
- What kind of world makes living and cognizing organisms possible?
- What makes some systems autonomous?
- What is the nature of life?
- What makes knowledge possible?
- What are the preconditions of a system to represent the external world? In other words, what makes perception possible?
- How to measure complexity among organisms?
- What is the principle of evolution?

Any learned reader will begin to doubt after reading the above list that I am attempting an impossible task. My objective is not to achieve a seemingly impossible and utterly ambitious task in this single essay, but to attempt to communicate that the alternative foundation being built is capable of *paving the way* to understand the above fundamental questions. We know that answers to these questions may also raise other new questions. Since the issues of life and cognition are known to be complex, I am aware that plenty of residue will undoubtedly be left unanswered after this essay. So what needs to be seen is whether this alternative foundation has the *potential* to address these questions. Therefore the arguments forwarded in this essay will attempt to demonstrate the *potential* of the model to tackle them, rather than *work out the details* of how the model takes care of each and every situation. In this sense the objective is purely to lay the foundation and scaffolding and not to build the entire edifice.

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

Contrast this statement with: "The world is everything that is the case."[27] 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.[1] 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.[2] 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,

[1] 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.

[2] This view is generally called in philosophy of science as 'semantic view'. Bas van Frassen's articulation of this view is the most popular.[22]. More details on the constructive nature of scientific knowledge, and a possible method of construction are discussed in [8].

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.

2 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[3] 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.

Postulates

1. **Multiplicity:** There are several Becoming-Beings in the possible world.
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).
4. **Perturbation:** Each interaction transforms the Being.
5. **Invertibility:** The transformed Being may invert to the original state of Being if the former has an inherent mechanism to repair the perturbation caused.

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

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 ontology of the world.

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.[4] 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*.[5]

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

[5]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.

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*. 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 microcosm *and* 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.[18]

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 don't 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.* 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.

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.

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.[6] 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. 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.

[6]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.

3 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.[7] 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 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.

4 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 mate-

[7] 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 [8].)

rial 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 do not know of any organism that survives exclusively on the energy that comes from IP interactions. 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 don't 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 and cognitive phenomena. We will return to this interpretation later with specific examples particularly in the context of explaining autonomy.

5 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. Some of the energy is dissipated into heat which cannot be recovered. 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 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.

One of the main ways of counteracting the increase in entropy is by increasing chemical bonds (by IT interactions). By trapping the energy 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. But we have no evidence to believe that living systems are moving in that direction. On the contrary, what seems to be happening in living systems is conserving and maintaining whatever identity exists. In the absence of this conservation the Being transforms into another Be-

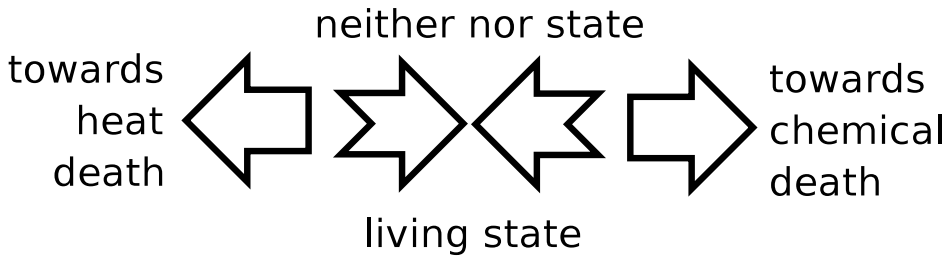

Figure 1: A Being is a neither-nor-state counteracting the two possible interactions

ing. This is because there exists another 'misery', apart from the direction of thermodynamic equilibrium, another direction of, what may be called, *chemical death* in contrast to *heat death*. This is reflected in the world in the formation of chemical bonds. Under certain conditions the Being cannot help but combine or dissociate.

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 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 8). 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. Living state is therefore defined as a product of counteracting *both* identity preserving and

identity transforming interactions: a *neither-nor-state*.[8] Prigogine's idea that self-organizing systems are far-from-equilibrium is therefore a half-truth. Kauffman's definition of living state as being at the edge of order and chaos is also not closer to truth. Using his language, I propose that *biological order* is on the edge between *chaos* on side and connectedness of *crystalline order* on the other. What then is the mechanism of maintaining the identity by opposing the two kinds of "death"?

6 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 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 a process P and its inverse $\widetilde{P}$ are part of the same system.

[8] Metaphorically it is like a tug of war between thermodynamic equilibrium and chemical variation. It is like a snake with heads on either end of the body. It is like a helical string extending in two directions.

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.

7 Dialogical invertibility is the logic 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.

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 bonds form and break at a constant rate. Associa-

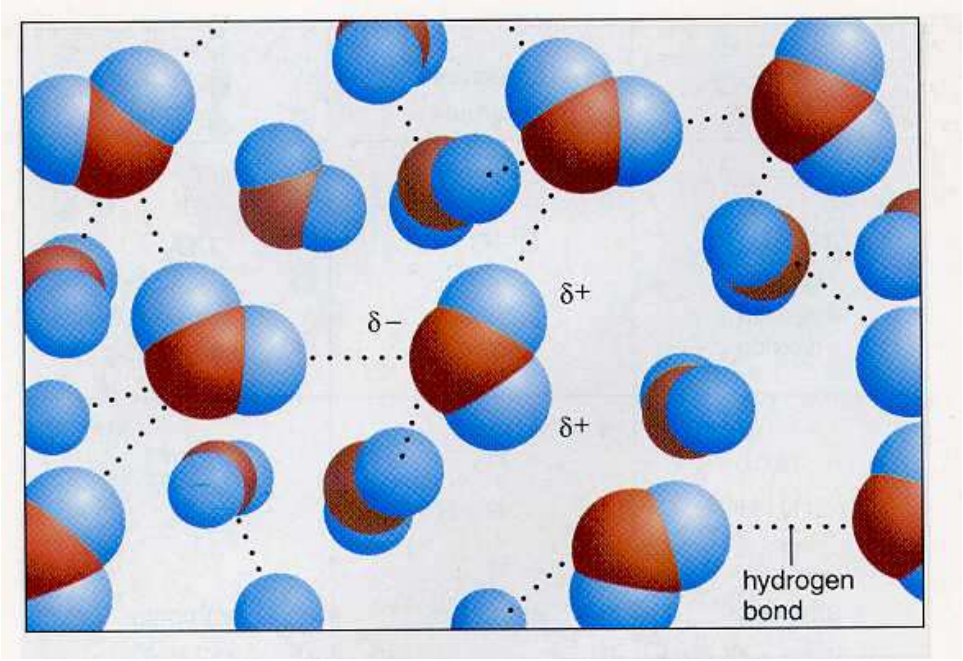

Figure 2: Water: Enabling space of life

tion 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 temperature 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.

Water, apart from being a temperature 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. This is possible because of 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 don't 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.

There are two conditions under which dialogical interactions take place:
1. when there is an abundance of amphoteric and amphipathic Beings or
2. when there is a single large macromolecule with several amphoteric and

amphipathic groups. This amphoteric and amphipathic nature is a neither-nor-state. Under the first case, when a single system attains two opposing properties one of them effects the other and vice versa. Under the second case, a *part* of the system effects the other. 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. Interstingly 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.*

Why 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)[13]. 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. Thus energy dependence of these dialogically invertible interactions is 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.

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 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 energy 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.

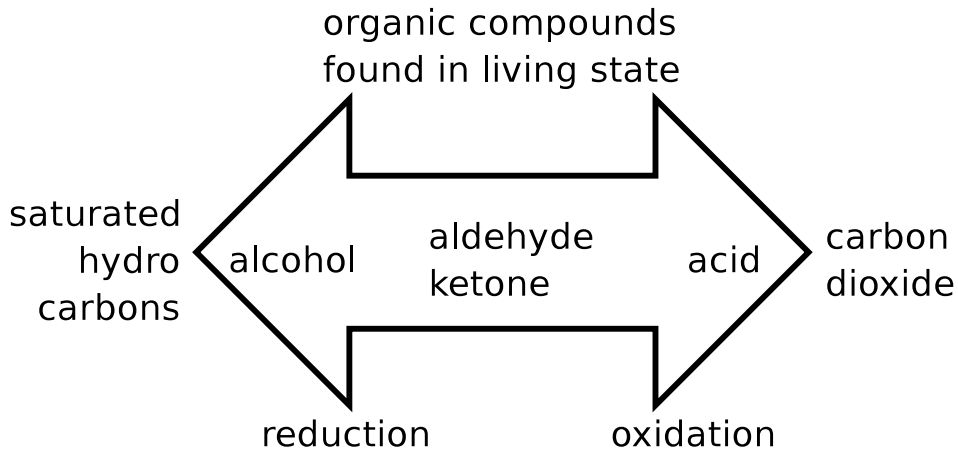

Figure 3: The oxidation and reduction states of carbon. Extreme oxidation and extreme reduction of carbon are avoided in living state. All of the metabolites in the living system are from the middle space.

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 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 the 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.

8 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)[7]. 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[12, 11]. 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)[15]. 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 systems, and the organization that defines them as unities in the space of their components, the autopoietic organization.[28]

Autopoietic systems are also organizationally closed, i.e., they have a circular network of interactions, rather than a tree of hierarchical processes.[23]

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 interacts 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 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

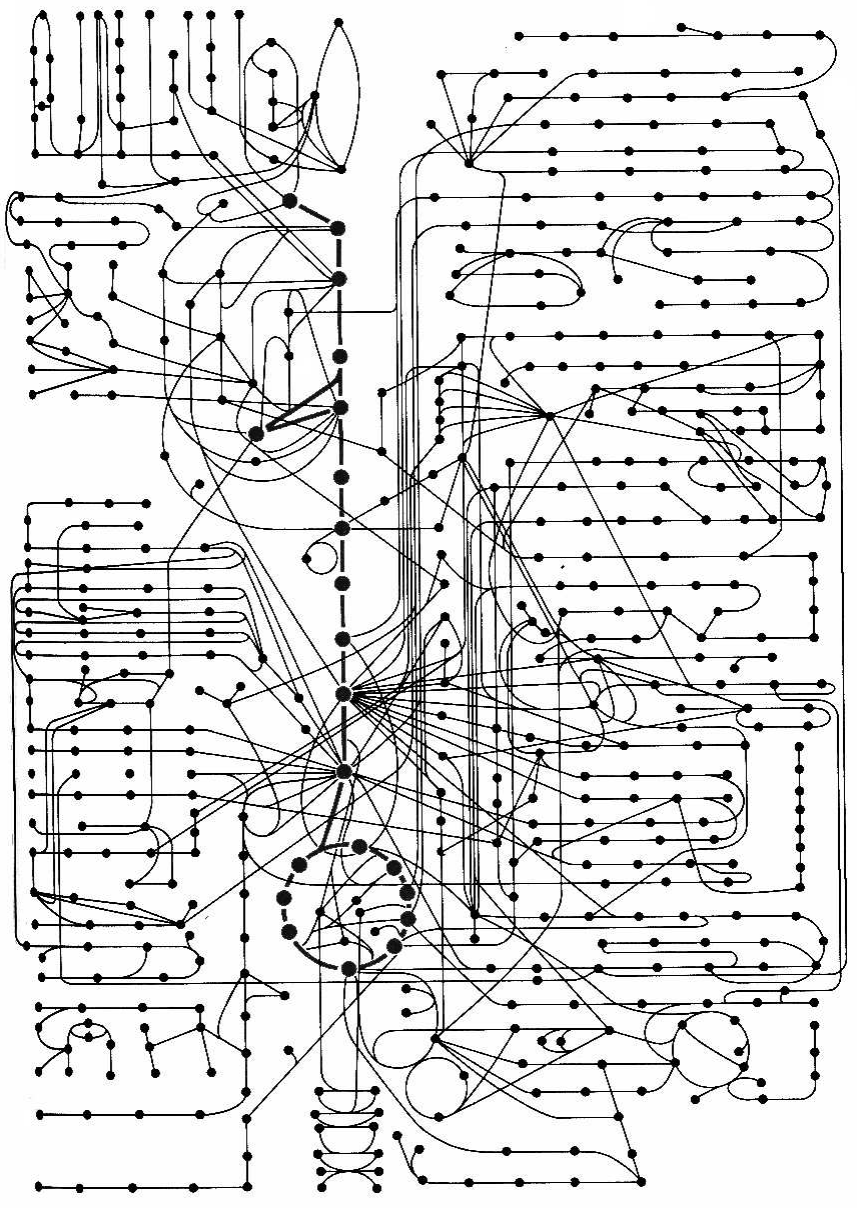

Figure 4: A diagram showing the map of various interactions taking place in a typical cell. Each node represents an enzymatic biochemical reaction. Diagram from *Molecular Biology of the Cell* by Bruce Alberts et.al.[1]

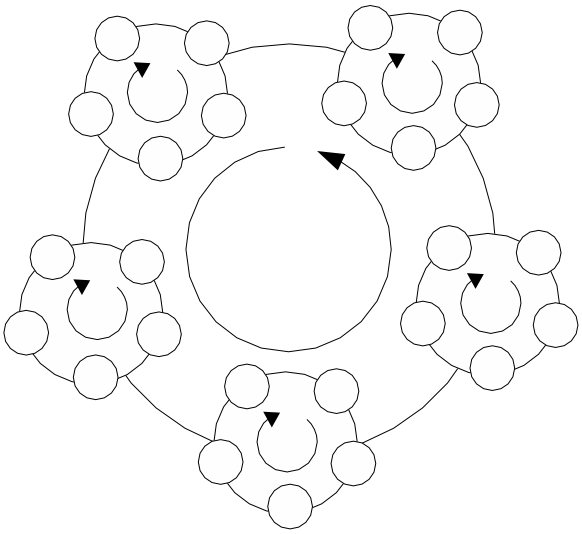

Figure 5: Metabolism is reproduction of dialogically invertible macromolecules (proteins, RNA, and DNA), which in turn catalyze the reproduction of other metabolites in a cyclic manner. Each circle in the figure represents a cyclic metabolic pathway reproducing a metabolite of another cyclic metabolic 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[7].

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 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 to do all the work.

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 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*) is not justified, for 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 the only 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.

There is another way to look at the picture. Consider DNA as a complex system 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*.

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. Also it seems that 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 cant sustain a moment without external supply. Artificially made

machines are mostly of this kind since they are linear and don't generaly form loops. 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.[9] 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 (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 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 re-producing 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'.

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

[9]This point was also made by cybernetic thinkers (See [25])

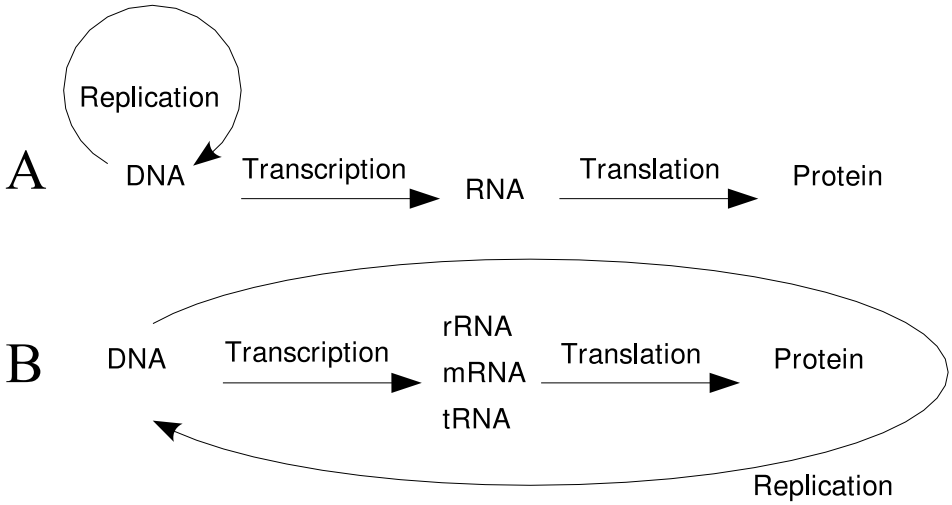

Figure 6: Comparison of the received central dogma (A) of molecular biology with its appropriate representation (B).

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 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 $\rightarrow$ RNA $\rightarrow$ 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

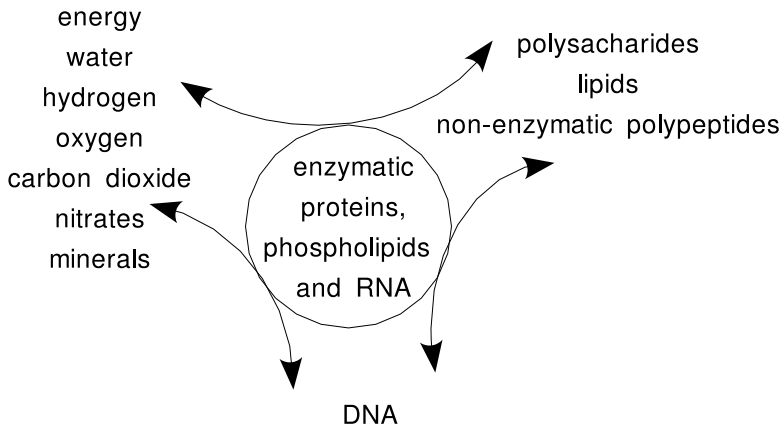

Figure 7: Alternative Central 'Dogma' of Molecular Biology: An ideal cellular metabolic network seemingly terminates at three nodes: 1. the energetic inorganic simpler molecules on the left, 2. the energy storing complex polymers on the right and 3. the information storing polymer DNA (deoxyribo nucleic 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.

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 $ldots$, the entire cell must operate to replicate DNA. Artificial replication of DNA in test-tubes is a case where all the resources

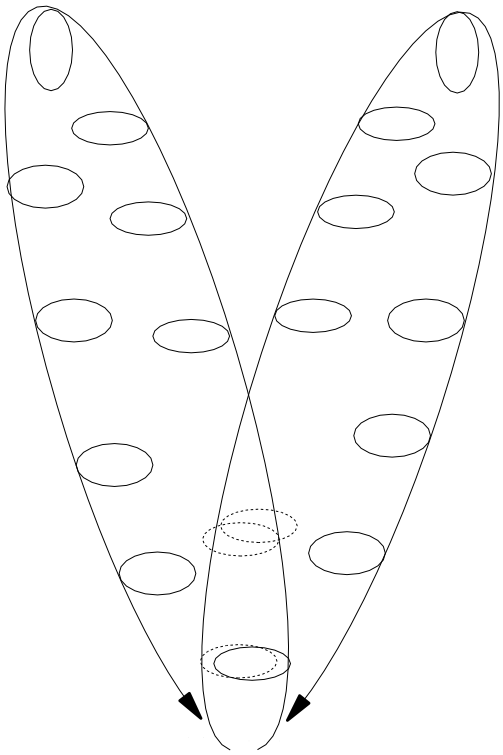

Figure 8: Each DNA replication is at the terminal node of all the reproduction processes, and is associated with a complete replication of the entire network of the cellular machinery.

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 should 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 as shown in the figure 8.

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 elabo-

rated 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 turn our attention to cognition in 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 proteins, and RNA is the problem of origin of life. We cannot deal with this complex question here but wish to leave by pointing out the direction. Views on origin of life are divided into *metabolism-first* or *reproduction-first* approaches–in other words—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 is 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.[10] 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,[2].)

He suggests that apart from genotype and phenotype, there exists a *ribotype*, the codemaker. I suggest that instead of distinguishing the two independent

[10]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[2].

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 closure and conservation.[11]

[11]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.[8]. Emmy Noether's proof, that every conservation theorem is a symmetry principle, is in this regard very interesting.

9 Adaptation, complexity, autonomy, and information processing are various manifestations of invertibility.

Long list of apparently different phenomena to explain. But the hallmark of a good scientific model is that it can do so. Invertibility model is a powerful metaphor and is more like a mother (generative) structure (a term often used by Bourbaki school of mathematicians and Piaget). I will attempt to indicate in this section how dialogically invertible systems are capable of performing the above mentioned characters of complex systems, particularly living Beings.

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 temperature 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 in-

fection 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 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 don't 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 [12].)

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.[12] 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

[12]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.

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.

What conditions make information processing possible? If for every one cause there is only one effect, or if for every one cause there is always two effects in a determinate way, we are talking *rigid* state of affairs. In a web of metabolic cycles, a single perturbation can cause several effects, often dissimilar effects. A good example is the cascading effect found in the peptide hormone action, that involves *messengers*, which in turn perturbs some other system and so on. In the process the information propagates and most often gets amplified. Information propagation doesn't need amplification of this kind. But, the point to note is that an external perturbation is not taken *into* the system, but it effects the system causing some persistent effects within. One of the important conditions of *representation* is that what is represented is not the object but something else, and the representation could live longer than the time of object's contact with the system. It is also important to note that the same object at different times produce different effect within the system. Therefore for generating information we need a kind of events that are not *law like* and rigid. Events may continue to be physical, but they are *anamolous*. This expression is borrowed from Donald Davidson's famous essay on *Actions and Events*[5], though he did not apply this for information but for mental events. In fact Davidson's analysis of autonomy also suggest that the nature of physical space where these special manifestations appear must not be rigidly law like.

10 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 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 Be-

coming 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 [8]. 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.[13] 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[8].

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

[13] 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 [8]).

emerges from the ever Becoming complex systems can be described mathematically.[14] 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.[21]

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. 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 [28].

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.

[14] 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.

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[26].

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.[12] 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. 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. But not really. A single perturbation can cause so much of internal flux, and some times even after the perturbation is absent, the internal work cycles continue to operate. Internally generated work cycle can also be causes for other work

cycles. Can this *re-representation*[15] account for thought? Operating in the absence of a cause may look like a problem in the model. If one perturbation can cause only one work cycle, it is a simple cause-effect model. But the current model is that a single perturbation could cause a chain of inter-related work cycles. Some of the perceptions may cause, some where deep in the system, a clock work of cycles making the Being feel an 'echo'. Can this pattern explain memory? While some perturbations have amplifying (cascading) effects, while others gradually die. Some of them might induce a reflex action. Some times same kind of perturbation may have different work cycles. Dissimilar perturbations may produce similar work cycles, and similar perturbations may generate cascading but similar work cycles. One work cycle may cause another. This way there are a variety of possibilities. Which possibilities cause what kind of effect remains to be worked out.

Pavlovian conditioning takes us to another aspect of knowledge, namely, anticipation. This is when Beings begin to make symbolic associations between things. If a metabolic work cycle can begin without food, or just a thought of it, it suggests that representations can also generate similar work cycles.

Accounting for representations is not enough. Relations between representations to produce generalized beliefs, inductive reason, logic ... Cognitive scientists are attempting to understand the biological basis of several of these questions. Learning models based on neural networks (connectionist) are also sufficiently promising to answer some of these questions. Shannon's information theory is another coherent and interesting model. Relations to these models to the current model are being worked out in the context of cognitive development.[16]

Consciousness, the awareness of being aware, is another perennial problem. We have no space to deliberate on this here, but I will indicate in one line the nature of my position. I tend to believe, based on a number of recent developments in cognitive and developmental psychology and the insights of philosophers like Wittgenstein and social constructivists, that it is a product of social reality and not biological. To be aware of ourselves we need a community of interacting Beings around. These interactions are lot more weaker than hydrogen bonds. But make substantial difference in the

[15]This expression is borrowed from Karmiloff-Smith's model of cognitive development in her work *Beyond Modularity*.

[16]I will be presenting a critical review of the various cognitive models in a conference to be held in December 2004 at Goa, at an international conference to review research on science, technology and mathematics education, epiSTEME-1, http://www.hbcse.tifr.res.in/episteme.

emotional life of a Being without much change in biology.

When we address the problem of the evolution of complex systems it is necessary to consider not only the concrete systems, but also the complex semantic systems constructible by the cognitive systems like the human being. Scientific knowledge differs markedly from the phenomenological (direct) forms of knowledge. Recent debates in philosophy of science have at least one clear message that scientific knowledge cannot be arrived at by inductive logic. Clearly after the fall of inductivism most philosophers of science agreed with Karl Popper that the context of discovery is highly creative, therefore illogical or irrational. No logic of discovery, they argued, can explain the origin of new theories. This view however presupposed that the only rational form of reason is deductive logic.

Though Popper was correct in holding that *true* scientific knowledge cannot be generated by inductive or by any other logic of discovery, it is however possible to construct *meaningful* definitions, models, and physical systems by means of a constructive logic based on a logical operation, *inversion*, a species of logical opposition distinct from *negation*. The distinction between negation and inversion can be brought out by the general principle that C and inverse-C, where C is any concept, necessarily coexist or covary in the same system, while it is impossible that P and not-P, where P is any proposition, can be a part of the same propositional system. To highlight the difference it can be contrasted with the *principle of excluded middle* which is the basis of deductive logic, while the nature of inversion based identity can be postulated by *the principle of included opposites or extremes*. I have argued that this principle forms the basis of a *logic of construction* of *models, scientific definitions* and *physical systems*, and their eventual development [8].

These proposals are mere indications of how a model based on invertibility and the principle of included contraries manages to address various phenomena pertaining to complex systems.

11 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 un-

falsifiable proposition.[17] 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 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

[17] 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.

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 proceses) 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 n-dimensional 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.

12 Madness must come to an end somewhere!

Of course not in a pathological sense! But in the sense of not being able to get out of the clutches of a model which appealed to my scientific imagination. As Kuhn says, you begin to look at the world in a different light after that creative moment—when 'infected' by a conceptual scheme. But my training in philosophy helps me to get out of it occassionally and see the light of other models as well—wandering at the margins of models.

The way I love to approach a problem 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 is an object that a subject may know it, and what are subjects, that they may know an object.* (See MecCulloch [16].) 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 *mechanization of the world picture* that life and congition continue to slip away. I tried to answer the problem of life and cognition basically following the same method but with an awareness of that method. The method is *inverse reason*.

This work is an extension of inverse reason to understand the mechanism of constructing living systems. I proposed inverse reason, a logic of synthesis as against analysis in my first attempt to do philosophy: *Role of Inversion in the Genesis, Development and the Growth of Scientific Knowledge* [8]. The principles of contradiction and excluded middle, the bases of

logic, are about analysis, but they preclude *methodologically* any possibility of accounting synthesis. I argued in my earlier work that another species of opposition, inversion as against negation, based on the principle of *inlcuded contraries* where the opposetes exist together explains how concepts, as against propositions, combine. We have no space to discuss that here, but interested readers can find the details in [8].

Originally I began developing this model of life as a challenging problem of implementing the proposals made in that work, where it is claimed that a logic of construction is possible. If I know a logic of construction, can't I use it to develop a new scientific model to explain some of the unanswered problems of science, instead of a post-hoc reconstruction of the discoveries alrady made? Being a biologist I began working out a model of living systems. I first published this idea in an half-baked form in a conference on the evolution of complexity [9]. This work I suppose is baked better than that.

It is very likely that I am taking a risk, by connecting these two works, one of epistemology and another of ontology. The risk is, one may fall or fly along with the other. But what is wrong in playing the game? With a fear of loosing we cant play any game. If it appeals to others there is a chance that it may take off the ground.

Is the proposed model too simplistic to take care of not one but several complex problems? History of scientific ideas indicates that in order to tame several not so well connected domains under one model, the assumptions made must be metaphorically strong enough to find instances in several domains. Generic models are simple, and often counter-intuitive.

But what is the problem that this model is attempting to solve? Aren't the existing models doing well, even though they account for a restricted domain? What is wrong with one good working model for each domain? Why should we have a grand unified theory? The main problem, I think, is not that the existing models of biology don't reduce to each other, or they don't have clear connections between them. The problem is a lack of *general logic of construction*. The proposed model offers one. A logic of synthesis, as against analysis, was not in place both in science as well as in logic. But the matter of fact is that we see construction everywhere. In mathematics, in our thought, in the world out there, it is ubiquitous. No one proposed a satisfactory answer. On the contrary the intellectual atmosphere forbids it, and attempts to seek an answer to this problem were ridiculed. Darwinism for ontology, Popperianism for epistemology are the recieved views. They abhor any possibility of a method in creativity or construction in thier respective domains. Recall Darwinism's stance that how variations come into being is not in the scope of a theory of evolution, but given variations the

rest is taken care by natural selection. Similarly, Popperians argued that how new ideas come into being is out of the scope of not only logic but whole of philosophy, but once the ideas are given the logic of deduction takes care of which of them explain the phenomena. For a long time inductive logic was thought to be the way to go. But we have enough evidence to show that scientific ideas in particular are not arrived by induction. How did they arrive remained not only a problem but a mystery. Charles Peirce's abductive reason remains today the best bet, which doesn't solve the problem, but says the phenomena are best explained only if we suppose the hypothesis. This still didn't explain how the idea came into being in the first place. This is the *poverty* of the dominant philosophical wisdom.

In the physical domain, Linus Pauling's ingenious explanation of sharing what each atom lacked to reach an inert gas configuration took care of chemical combination. This is an important milestone in understanding how things combine. In fact in this principle lies a directionality, to reach a state of *inertness*. Initially I thought it could explain, but the phenomena in nature are not known to be moving in this direction. Also, chemical combination is too energitic to take care of the plastic constructions in biology. What is halting this to happen? Obviously inertia. Interestingly there are two faces of truth lying in the law of intertia. One is to continue to remain in the same state of motion. The other is to resist external force, which depends on mass. How much mass-energy a Being has explains how much force it can resist. Thus even in this principle lies an element of *resistance*, to remain in the current state. This is not a permanent way to remain unperturbed, for the multiplicity postulate allows other Beings to perturb it. Whatever be the magnitute of resistance (mass) the Being could, is the beginning of complexity. This appears to me, in relation to living state, as the zeroth order of complexity. But we all know that the atoms that give this zeroth order of resistance have another universe of complexity. So the composition of mass units cannot be explained without recourse to arguiably the most creative constructions human being ever created: quantum physics. This is a domain where we not only see IP interactions, but also IT interactions. All these interpretations drived me to reach a conclusion: There is a state which every Being of nature prefers: *to reach a state that maximizes work with minimal energy.*[18] This is possibly the directive principle of nature. Don't abhor teleonomy particularly when it explains *thy self*. Our very existence is a fact on the face that this world allows purpose a possibility. We exist in that state. It is our challenge to figure out how this state comes into being

[18]Is this another version of the principle of least action?

without mythology.

The challenge that remained is: What is the phase space that makes a Being to reach this state possible? This paper is an attempt to answer this question—*Tractatus logico vitalis*. Whether I succeded in doing this or not is left to you, the reader. Needless to say, lot more work is needed to not only substantiate by identifying and interpreting various phenomena but also to build a mathematical model of this described ontology. I deliberately used a jargon close to science than philosophy and metaphysics, to appeal the imagination of scientists—the problem solvers.

There exists, I think, only one way of doing more work with less energy without violating the principles of thermodynamics. *Recycle. Revert. Repeat. Regress. Recurse. Repair. Invert. Loop*. As a whole there is a plenty of recycling in the biosphere—the wisdom of ecology. But that will not make a Being reach the desirable state. What we need is:*recycle within the Being*.[19] And this is self-re-production.

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 Beings in a very large number with lesser complexity try to perturb the Beings with greater complexity, complex Beings tend to loose their order by dissipation—first tendency. In that very process, some times Beings with less complexity manage to get together to resist the first tendency by reaching a state of inertness by chemical bonding–second tendency. In a world where larger Beings continue to get perturbed, some of the larger Beings develop an ability to function by breaking and forming weaker bonds within itself in an abundant pool of energy and in an enabling buffering media. 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.

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[19]No wonder we need a circular wheel to reduce mechanical advantage. Nothing can be a machine if it cannot invert to a base state regularly. Arguably the very first scientific insight that made Archimedes to run naked was this. See my reconstruction of Archimedes's discovery in [8]

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