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"*What is life 2.0*" playing the sudoku with a new tool box: Metabolic Holons, Optionality and Codepoiesis

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Extended Abstract

This paper puts together several theoretical concepts emerged after the writing of the seminal paper of Schrödinger. As suggested by Pattee "*Life is matter with meaning*", therefore in order to study life we have to study first of all the meaning of "meaning" in a process of autopoiesis taking place without human brains. Part 1 illustrates the implications of the concept of ***negentropy*** - the revolutionary input of Schrödinger - that can be better appreciated when integrated with the concept of ***autopoiesis***. The two combined explain the existence of purposes and beliefs in living systems. ***Biosemiotics*** deals with the commuting between information and physical processes taking place across different scales – "local/meso" ←→ "meso/large". We can imagine the semiotic process of life organized over the three domains: (1) REPRESENT/syntax – where perceptions and representations are based on "types"; (2) APPLY/pragmatic – where action is done by "instances of types" (material entities); (3) TRANSDUCE/semantic – where the commuting generates and updates the definition of identities used in the semiotic process (life itself!) recorded in coded information. In the pragmatic step life observes and interacts with the external world in order to check the validity of beliefs. It should be noted that the part of the "external world" relevant for the updating of meanings - the TRANSDUCE/semantic domain - is not studied by reductionism. This explains why non material "entities" such as meanings, purposes, essences, are not considered as legitimate entries in the scientific discourse. Part 2 illustrates more in detail the mechanism used in the step TRANSDUCE to assign meaning to the information used in the semiotic process. The concept of ***holon*** is crucial to understand the elusive nature of the semiotic process that continuously commutes between physical processes (pragmatic) and information (syntax). A holon defines two ambiguous mappings between:

(i) "types" (essences) and "instances of types" (material entities realizing the type); and

(ii) "structural types" (black-box/parts defined at the local scale) and "functional types" (black-box/context defined at the large scale). This ambiguity makes it possible to assign meaning to an "encoding" – mapping a structural type (information) onto a functional type (process) – that results effective to achieve a purpose (that confirms a belief). The commuting between information and physical processes – e.g. recipes (DNA) used to make processes (metabolism) making recipes (DNA) – takes place simultaneously across different hierarchical levels of organization. This makes it possible to generate a ***Sudoku effect***, in which *direct information* – i.e. how to make an antelope, written in the genes of that species – can be integrated by *mutual information* – i.e. what the antelopes do, recorded in the information space of the rest of the community/ecosystem to which the species belongs. The structural type of a holon is defined by genes at a lower level and scale, whereas the functional type is defined by the niche of the species by processes occurring at a higher level and a larger scale. This coupling establishes a vertical relation across levels of organization expressing behaviors at different scales. In this framework the ***adaptive cycle*** of Holling can be reinterpreted using the concept of holons and holarchies. The relative importance of upward causation (bottom-up transmission of information tracking biophysical gradients at the local scale) and downward causation (top-down transmission of information tracking biophysical constraints at the large scale) determines the evolution of life. Finally, the concept of ***optionality*** introduced by Taleb explains how is it possible for life to play with wrong models and still win. In a semiotic process operating under heavy doses of uncertainty, the holonic organization implies that when an innovation is successful, new useful types can be amplified to a very large scale, whereas when the innovation is a failure, the loss is limited to a realization of a defective instance of a structural type at the local scale. The conclusion of the paper is that the study of life should not be based only on the analysis of what goes on "on the bottom" (molecular biology) but also of what goes on "on the top" (ecology). We have to study the mechanisms capable of generating meaning in the semiotic process. This is exactly what the new field of ***codepoiesis*** should do.

Key words: life itself, negentropy, hierarchy theory, holons, adaptive cycle, bio-semiotics, metabolic systems, codepoiesis, optionality, Sudoku effect

1. Why do we need a new box of epistemic tools to deal with the question "what is life"

1.1 In order to understand "what is life" we have to escape the cage of reductionism, there is also "plenty of room on the top"

On December 29th 1959 (before winning his Nobel Prize in Physics) Richard Feynman gave a talk at the California Institute of Technology (Caltech) in which he made the famous statement "there is plenty of room on the bottom" to be explored by science. Later on this statement became a manifesto indicating the direction of scientific research in the era of modernity. Since then scientists with different interests, those studying life and those studying machines, seem to have remained stuck on the idea that scientific success depends on a deeper and deeper analysis of the mechanisms and the components of the systems to be investigated. As a matter of fact, the idea of moving toward the bottom was certainly not new. It had already been indicated by Cartesius many years before – *"divide each difficulty into as many parts as is feasible and necessary to resolve it"*. This strategy called "reductionism" is at the basis of the technological progress experienced in the second half of the XX century. As a matter of fact, it has been exactly the technological progress of the XIX century that made possible to better explore mechanisms and systems at a smaller and smaller scale. Overwhelmed by this success story also those working in biology have been focusing on the analysis of mechanisms at the small scale (the proliferation of different types of "omics") and technological studies got fascinated by the possibility of generating "nano" mechanisms. In this essay I argue that if we want to understand better how life works we should also look at the opposite direction: there is plenty of room on the top to be explored by science.

A quote, from E.P. Box - "*all models are wrong, some are useful*" (Box, 1979 pag. 202-203) - can be used to illustrate my point. This quote flags the existence of an unavoidable distinction to be made between *formal representations* (models) and *useful semantic perceptions* of events (the insight gained when using useful models). The latter are associated with the choice of relevant narratives (explanations of causality that help in dealing with a practical issue). Box, with this quote, wants to give a warning about the fact that what is important in science, especially in applied science, is not the accuracy of the formal representations of events. Formal representations are wrong by default, since no system can be represented exactly the way "it is". That is, a formal representation cannot consider all possible points of view and observable features of "entities" observed in the external world. Let alone if these entities are expressing different behaviors and becoming in time simultaneously at different scales. What is important in science is the usefulness of the narrative about what has to be observed: is the perception used to generate quantitative information meaningful and effective for the given purpose? This question faced by scientists is exactly the same faced by living systems. Microorganisms following a gradient of a chemical substance are using a very simple anticipatory model to guide their behavior – IF the concentration increases, THEN keeps going, IF the concentration decreases THEN stops moving in that direction. This simple model misses an enormous amount of potentially relevant information, however, most of the times it results useful for them. The quote of Box is essential because it identifies two key feature of life: (1) you must have a purpose in order to be able to check whether your anticipatory models are useful; and (2) you must have an option space of possible behaviours. To these two feature we have to add a third one (not related to the quote of Box): (3) when your anticipatory models fails you must be able to still get away with it. In this essay I claim that life is capable of: (i) generating processes and entities having a purpose – this implies that life is capable of checking the usefulness of recorded information; (ii) generating processes and entities whose characteristics are not fully determined by physical laws, but expressing behaviours determined by systems of control – this implies that life can learn; and (iii) surviving in spite of unavoidable large doses of uncertainty associated with the information space used when carrying out these two tasks – this implies that life can cope with ignorance and still thrive. I will introduce a few theoretical concepts to show how is it possible to achieve these three results.

If we agree with the statement of Box, then we can better understand the "mission impossible" faced by those trying to define or simulate life using formalizations. Formal representations can be handled using mathematics or information theory, however, when dealing with the issue of *purpose* and *meaning* formal systems of inferences are powerless. That is, a strategy aimed at understanding the mechanism generating meaning does not to coincide with the recipes of either Feynman or Cartesius. According to semiotics in order to assign meaning to a formalized piece of information it is necessary to commute between "the bottom" (making and/or observing the symbols), "the top" (transducing the symbols assigning to them a meaning for guiding action after having identified their external referents) and "the meso" using the information assumed to be meaningful for doing something, a physical process. In order to contextualize the information and to make it useful – e.g. for guiding action – we need to have some "intepretant". As a matter of fact in a semiotic process the "interpretant" has to play two different roles: (i) it has to interpret the symbols to guide action (transduce-apply); and (ii) after looking at the results of the action, it has to validate the used information, to decide whether or not the same information will have to be used again in the future (transduce-represent). This commuting done by an *interpretant* interacting with *the external world* is what is known as the semiotic process. It should be noted, however, that this interaction with the external world, in the semiotic process takes place in two distinct domains:

(1) the domain called "the other" – in the step REPRESENT/syntax perceptions and representations based on "types" are used to describe events taking place in the external world. In the step APPLY/pragmatic the actions carried out by "instances of types" (material entities) have the goal to observe and interact with the external world to check the validity of beliefs. In this domain "types" and "instances" are defined at different levels and scales – cells, organs, organisms, populations, ecosystems;

(2) in the domain called "the self"- in the step TRANSDUCE (semantics) living systems update the definition of identities used in the semiotic process (life itself!) as recorded within the coded information. It should be noted that this part of the "external world" essential for the semiotic process (the updating of meaning) is not studied by reductionism. This explains why non material "entities" such as meanings, purposes, essences, are not considered as legitimate entries in the scientific discourse.

In relation to the various steps of the semiotic process taking place within living systems science so far has been focusing mainly on the description of what goes on within mechanical processes taking place in the external world (on the bottom) – e.g. the writing and reading of written information at the local scale in molecular biology. However, science did not generate many useful narratives to describe how then this formal information is translated into meaning. As a matter of fact, reductionism has a systemic problem of handling the concept of "meaning" in the first place. In fact, *meaning* cannot be associated with any observable material entity and this is something that makes "hard scientists" quite nervous. Meaning belongs to the same class of entities difficult to define such as *life*, *language*, *love*, *the soul*, *the mind*. Science cannot deny their existence, but since they are not material and not observable using the physical senses they remain in a sort of "limbo" in the scientific discourse. In relation to this point, there is another beautiful quote related exactly to the relationship between life and meaning. It is a quote of H.H. Pattee that explicitly indicates the key role of meaning in the process of life: "life is matter with meaning" (discussed below). Personally, I find this quote a stroke of genius pointing at the direction to follow if one wants to understand in "hard" scientific terms what life is about.

1.2 Who is scared of teleology? The final cause has been around since the time of Aristotle

When I was a student of biology I was told, when studying the debate between Lamarkism and Darwinism, that the quite self-explanatory statement "the neck of giraffes became longer in order to be able to get more food in a given area" is scientifically wrong. More specifically, this statement is "politically incorrect" (and therefore wrong!) because accepting this explanation of causality would imply accepting that "teleology" should be considered as a factor explaining the existence of life. For this reason the explanation that evolutionary changes take place "in order to improve (specialize) the niche of a species" is not acceptable in science. Many of those that study life find unacceptable to say that living things act "in order" to obtain results. For this reason, the politically correct mantra says that random mutations, totally independent from the external conditions in which giraffes are operating, have in the past determined changes in the DNA of giraffes. Then these mutations were translated into changes in the length of the neck. Only at that point, *after the random mutation taking place*, natural selection entered into play. This mantra is based on a clear definition of a temporal relation: first the random mutation and then the change that results useful. To be honest I have never been impressed by the choice of this narrative to explain evolution. I do not mean that the politically correct narrative is untrue or misleading, I simply believe that the mechanism generating mutations is not particularly useful to understand or explain the process making possible evolution in life. In fact, I was convinced then and I am still convinced now, that in order to explain why the neck of the giraffe is long we should adopt a functional narrative: the long neck makes it possible for this species to define a "better" niche not overlapping with other herbivores operating in the same ecosystem. This "improvement" leads to a mutual benefit for the species and the rest of the community. In relation to this type of analysis the mechanism through which this change is obtained (how the increase in length of the neck was obtained) is quite irrelevant. However, at that time, being a student, I had to accept the politically correct mantra, since I was not able to articulate my uncomfortable feelings about the orthodox Darwinian explanation. Again in the orthodox explanation the individuation of the mechanism determining the change (the HOW) is right, but when this mechanism is used to justify the evolutionary direction taken by the neck of giraffes (the WHY), this explanation becomes not even wrong, but simply irrelevant. As a matter of fact, I had to expect a few years (after studying complexity theory and in particular hierarchy theory) before being able to understand the epistemological implications of multiple scales, and therefore identifying what I did not like about the "orthodox" explanation about the length of the neck of giraffe imposed on the students. Complex systems operate and evolve simultaneously across different scales and this implies an unavoidable epistemological predicament: the proliferation of possible perceptions and representations of events. Put in another way, you can describe human beings at the level of individual cells, tissues, organs, individual human beings, households, communities, nations, the whole humankind. Every time you chose a hierarchical level of analysis and the relative scale you see some aspects and miss other aspects. This implies that you must be prepared to find different non-equivalent explanations (narratives about the causality) for a given events. A self-explanatory example of this fact is given in Fig. 1.

Fig. 1 The co-existence of non-equivalent explanations of a given event

All the explanations of the specific event listed in Fig. 1 are legitimate and scientifically sound. Yet you would not use the explanation of the lack of oxygen to the brain when deciding how to tax cigarettes in a political debate or you cannot philosophize about the unavoidable faith of human destiny when working in an emergency room. In the maze of possible narratives about causality, depending on the purpose of the analysis, you have to individuate the explanation that fits your purpose at the moment of using an explanation. Different narratives, explanations and relations of causality referring to different scales and different dimensions of analysis can all be true or wrong, useful or misleading, depending on the context in which and the purpose for they are used. The implications of hierarchy theory are that each event - the long neck of giraffes - can have multiple non-equivalent explanations, a fact already discussed by Aristotle centuries ago when reflecting on causality. Personally I believe that the excessive focus given to the importance of DNA in the discussion about life seems to miss the point that the DNA of an antelope is not about "what antelopes are" or "what antelopes do", but rather it is about how to make material instances of antelopes while keeping record of the blue print used. That is the information written in the DNA of an organism is about how to "realize an instance of an equivalence class" – a process necessary to preserve the meaning of a given coupling of a structural type (populations) and functional type (niche) associated with the existence of that species. The DNA of an organism carries information about the fabrication of an instance of the typology of the species but it cannot and should not be confused with "what is the essence" of a given organism. The essence is the general condition of the organism, which can only be obtained by ***preserving the process that is used to assign a meaning to that information***. The meaning of this information is guaranteed by the possibility of expressing in time an equivalence class of realizations (instances) of the structural types (populations) associated with the species capable of expressing their expected functions in their niche that in turn requires functioning ecosystems in which the species operates to be preserved in time. In this definition, what "antelopes are" and "what antelopes do" is described by the mutual information about antelopes contained in the DNA of the other species interacting within antelopes, at a given space-time domain (the description of the functional type – the niche) – and in an expected set of boundary conditions (i.e. antelopes operate in terrestrial ecosystems, dolphins in aquatic ecosystems). This mutual information is preserved in the community within which antelopes operate. This result is possible because of the congruence of the information replicated and expressed at different scales against a common set of thermodynamic constraints. Put it in another way, the meaning of the information carried out by living organism depends on the possibility of establishing an integrated set of biophysical processes (the metabolic pattern of individual organisms, of ecosystems, of biomes and of Gaia) controlled by the information that has to be preserved that can remain in quasi-steady state across different scales. When considering the cascade of biophysical processes of autopoiesis operating across different scales "the information carried out by living organisms" is no longer represented only by the simple coding found in the DNA of genes of individual species, but also the organizations of genomes, the organization of genetic information on taxa, the organization of communities reflecting the specific available taxonomy that in turn reflects the feed-back coming from biophysical constraints provided by boundary conditions experienced by ecosystems now and in the past.

The consideration of the interaction among entities defined at different scales and operating simultaneously at different levels of organization generates a clear epistemological impasse (Giampietro et al. 2006): in this complex of interactions it becomes impossible to define a simple direction of causality. Rather we should expect impredicative relations (such as chicken-egg paradoxes) and the impossibility to describe events as happening "before" or "after" when considering all the possible scales. For example, human babies develop teeth when they are still drinking milk. Babies do so, because the human species "knows" that sooner or later individual human beings (now babies) will have to chew food. In this example, the human species (an entity defined at a scale larger than the one used to observe babies) provides information through the genes passed to the babies referring to their future states. What is the future, when adopting the narratives of a baby (chewing food) is the past when adopting the narrative of the species (we have been doing so for centuries). Therefore, the interaction between two entities operating at different scales (human species and individual baby) can imply the generation of anticipatory capability in the entity operating at a smaller scale. However, it should be noted that this transfer of information about "future states" is possible only if the two entities considered are "types" – defined out of scale and not becoming in time! In fact, whenever we deal with special instances of a type we discover that instances are by definition: (i) scaled (they must have a size); and (ii) subject to irreversible events – they are becoming in time (ageing). We can predict the future of types associated with an expected pattern of development – e.g. babies, children, youngsters, adults, elderly - but nobody can predict the future of a specific instance. A realized instance of a type can have an unexpected accident any moment!

This concept can be clarified by introducing a very effective distinction found both in oriental philosophy and western philosophy:

(i) there is an "external reality" that we cannot fully know. Because this would require considering simultaneously all the possible scale, dimensions and observable attributes. This is called the TAO in Taoism or the universe of "noumena" in the Kantian tradition. This "external reality" is continuously changing and cannot be predicted. The "instances" of types – are entities that humans can recognize, but that cannot be fully perceived and represented, because: (a) any material entity belongs simultaneously to several "types"; and (b) each material entity is special because of its history;

(ii) there is a "perception of the external world" that is based on the available repertoire of types, narratives and conceptualization, that is the basis of our knowledge. This is called the NAMED in Taoism and the universe of "phenomena" in the Kantian tradition. Using this distinction we can say that we can only make analysis and predictions in relation to the NAMED or the universe of phenomena – our perception of the external world – and not in relation to "the reality". As it will discussed below the same predicament applies to the information generated and used by living systems.

The example of the anticipatory capability of babies developing teeth before needing to chew illustrates the need of introducing new concepts when dealing with analysis of life. We need a more complex epistemological tool kit to perceive and represent the mechanism of life. For example, in the discussion about baby teeth I have adopted a narrative that is based on the acknowledgment of three distinct "entities" quite different in their nature:

(i) *individual instances of a baby* – an instance of a type (an observable material object) refers to a known typology (an observable type) useful to describe an evolutionary stage of humans or to recognize an instance of it. This object is observed now and at a local scale;

(ii) *expected characteristics of the typology-baby* - an "observable"/"recognizable" known set of attributes (pattern) useful to recognize and describe an instance of it. This type (out of scale) is associated with an expected perception of human beings in their early evolutionary stage. The type can be recognized when observing the features of a given instance (pattern recognition). The validity of the information associated with the type "human baby" when used to characterize the special observed instance expires in about 1 year (the baby is no longer a baby after this period);

(iii) *a taxonomy of observable known typologies capable of generating a set of expected perceptions associated with the "names" used to recognize and to talk about human beings* – an integrated set of known typologies useful to recognize and describe instances of humans –– e.g. babies, adults, elderly, women, men, pregnant women, white men, etc.. It should be noted that the validity of the information about the types included in this taxonomy (not about the instances belonging to these types!) expires only on a very long time scale. The taxonomy of known perceptions of human types remains valid for centuries.

Using information based on types is essential, since it makes it possible to both identify an instance of a given type (a man, a woman, an adult) and study differences among instances of the same type (fat man, short woman, blonde adult). Depending on the speed of evolution of types, the expected characteristics of types have to be updated in time. When dealing with fast evolving types - e.g. the evolution of typologies of mobile phone – we have to update the type quite fast (e.g. every year) and this makes problematic the use of this information in the semiotic process. On the contrary, stable typologies of types – a tiger – can be assumed to be stable on a large time duration – e.g. centuries. The distinction between information about "types" and information about "instances" is of key importance if we want to understand the factors to be considered when studying life. When studying the functioning of life we should be able to clarify first of all "what is that is changing" (a type or an instance?) before getting into the analysis of "how is it changing". A systemic integration of the analysis of changes of types and changes of individual instances requires a much elaborated discussion than the simple analysis of the mechanism of mutations studied by molecular biology. As a matter of fact, nobody would study the functioning of the air transport sector, that makes it possible the safe operation of millions of commercial flights per year, starting from a detailed analysis of the mechanisms operating inside the airplane – e.g. how power is generated in the engines or what are the mechanisms making possible to operate the flaps at the moment of the take-off and landing. These mechanisms are certainly needed, but they cannot (and should not) be used to explain the development of the air transport sector.

After admitting the need of acknowledging the key difference between "typologies" and "instances of typologies" we are forced to acknowledge the existence of another complication. There is a key duality found when dealing with typologies. In fact, when dealing with life it is unavoidable to find always two types of typologies:

(i) structural types (associated with the expression of specific organized structures); and
(ii) functional types (associated with the expression of specific functions).

When dealing with life there is a systemic coupling of these two types in the organization of living systems. An organized structure is needed to express a function. At the same time nobody will invest resources in building an organized structure if this would not perform a useful function. So we can conclude that organized structures are produced in order to be able to express a function (design). This is the sensitive issue raised by the interpretation of evolutionary change suggested by Lamark. Lamark's identification of the mechanism used to generate new structural types (the HOW) was certainly wrong, but the narrative about the fact that one can interpret innovations and the improvement of existing structural type in relation to the achievement of a given goal (the WHY) is a legitimate one. As a matter of fact, let's imagine now to adopt only the basic explanations of mutations and natural selection in the strict Darwinian interpretation. Then we can say that a certain function providing an important advantage can be expressed, by chance – emergence - by an organized structure that was not originally produced for fulfilling that task. In this narrative, errors in the production of an instance of an organized structure, originally supposed to belong to a given structural type, result in the expression of a new characteristic capable of playing a new functional type. However, what is not explained by this narrative is how is it possible to associate this instance made by error (that is not a structural type yet!) to the new functional type (a new meaningful role played by this special instance) in its context. In fact, assuming that the genetic code preserve memory of the error and therefore can be used to stabilize the ability of expressing the new structural type generated by the mutation, this new structural types requires a context that makes meaningful the new function. That is the existence of a process that guarantees the reproduction, at the large scale, of the specific characteristics of the context determining as useful the new structural type.

In hierarchy theory the coupling of a structural and functional type generating a relevant "whole" is described using the concept of holon. This is an epistemological concept absolutely essential for the analysis of life. So we can resume the previous discussion by saying that the establishment of a meaningful holon in life requires operational coupling of a structural and functional type. This coupling in turn requires simultaneous adjustments of: (i) thermodynamic processes operating simultaneously across different scales – i.e. the metabolic pattern expressed by the mutant individual starting a new species and the metabolic pattern of the ecosystem within which the new structural type is operating determining the conditions required for expressing the new function – and (ii) the associated information space – i.e. the genetic information after the mutation must be able of replicating the features of the instances generating the new structural type. When looking at the holonic coupling implied by the generation of a new species we can say that: (i) the genetic code is required for reproducing the special characteristics of the deviant instance (generating several members of an equivalence class carrying out the mutation); and at the same time, (ii) a mechanism of coordination across scales is required for guaranteeing that the expected characteristics of boundary conditions (the niche of this new structural type) will remain the same in the long run. To achieve this result the semiotic process must be capable of integrating two different processes taking place simultaneously at different scales: (i) how to reproduce the new structural type (processes inside the local system), and (ii) how to reproduce the required boundary conditions (processes outside the local system). The concept of holon is important because in life the coupling of the two types of types is naturally ambiguous. This ambiguity is essential in order to be able to generate emergence (the generation of new "meanings") in living systems. This ambiguity is at the root of "radical openness" (Chu et al. 2003) of complex adaptive systems, a key feature needed to guarantee adaptability. This implies that depending on the circumstances, different organized structures (structural types) can be used to express the same function, or a given organized structure (a structural type) can be used to express different functions. Practical examples are illustrated in Part 2 when discussing the concept of holon more in detail. To make things more difficult the same structure can express different functions simultaneously at different scales or express different functions, at a given scale, but at different points in time when operating in different contexts. This ambiguous mapping "many to one" and "one to many" among types of types implies that it is possible to have a virtual infinite universe of possible definitions of holons – i.e. effective couplings of structural and functional types – when dealing with the perception and the representation of living systems. These definitions cannot be handled by using only syntax (formal definitions) because the concept of holon establishes a relation between two entities defined at different scales that can only be perceived and represented in different descriptive and logical domains. The mapping (on the information side) and the coupling (on the process side) between structural and functional type must necessarily be of a semantic nature. As result of this fact, the only way to assign a firm "meaning" to a given coupling of two types – e.g. a longer neck (structural type) makes more effective the niche (the functional type) of the giraffe – is to check its validity through a semiotic process. In fact, a semiotic process makes it possible to validate the information in relation to both: (i) the internal view – e.g. the blue print must be capable of generating a structural type that can express a useful function in a given context; and (ii) the external view – e.g. the mutual information about the functional type must be capable of stabilizing in thermodynamic terms the conditions making useful that function. This validation cannot be done from within the information space used to describe events from the internal view. Successful action carried out at a different scales and described in different descriptive domains is the only way to validate the meaning assigned to the original information. After being validated as a meaningful information in the given context, the genetic information associated with either the reproduction of an old effective function (e.g. in a genome replicated without errors) or to the emergence of a new effective function (e.g. in a genome in which a mutation has generated a useful change) will be replicated and used again to produce more instances of organized structures of the same type, expected to operate in the same context. It should be noted that the phenomenon of emergence in the information space of living systems is not only associated to mutations in DNA but it can also be obtained by any other mechanism determining a coupling between structural and functional types – e.g. centripetality in ecosystem networks discussed later on.

1.3 The semiotic process and bio-semiotics: how to generate a process making it possible to define as "true" of "false" formal statements about the external world

The information space used by life in metabolic networks – e.g. ecosystems - is organized like the SUDOKU game. Two different types of information are required to properly operate the system: (i) the information required to write a given number – e.g. 3 – in a given cell (how to make a realization of a structural type – the DNA of the antelope); and (ii) the information needed to know whether 3 is the right number in the right place within the grid – the mutual information about antelopes reflecting the expected characteristics of the relative niche. The second type of information - the mutual information accumulated in the Sudoku - is determined by the organizational structure (physical laws, grammars or systems of codes) operating across different scales (biochemistry, cell biology, physiology, ecology) and the accumulated history in the system. The combination of these two types of information defines both the relative size (quantitative) and the characteristics (qualitative) of the mix of metabolic holons operating in the living system. In relation to this process the information given by the DNA – when read at the local scale - provides only a few of the needed codes to generate the attractors (initiating conditions) guiding action. Many other codes are used to control the biophysical processes taking place across scales and determining favorable boundary conditions. Using the metaphor of the SUDOKU mutual information can be interpreted as determined by the numbers already written in the grid (the characteristics of existing species, the characteristics of the metabolic patterns inside the organisms, the set of biochemical reactions, organelles, enzymes) that combined with the rules of the game (the existence of physical laws determining thermodynamic constraints) generate path dependency in the progressive filling of the rest of the empty cells in the grid. When using the metaphor of the SUDOKU we can see that life has to be capable of handling information referring to different scales (very large, large, medium, local, micro), by running several versions of the Sudoku games one inside the other. In this process the role of grammars and codes is essential, since they provides the possibility of establishing a chain of different couplings – functional types coded in the NAMED (the information space) and the associated metabolic processes of structural types in the TAO (thermodynamic processes) – across different levels of organization and scales. This makes it possible to produce the various instances of types defined at different scales at the right pace (the turn-over of incumbent in the structural type of the various metabolic holons). Thanks to this organization across different scales it becomes possible to reproduce the equivalence classes of structural types (e.g. populations of a species or organelles within a given cell type) guaranteeing the compatibility across the characteristics of the various types expressed at different hierarchical levels of organization. On the process side, at the local scale, this requires producing agents (defined at the local scale) operating as nodes of established thermodynamic networks (defined at the meso-scale), that must result compatible with large scale boundary conditions.

The validation of this integrated information space is guaranteed by the semiotic process that continuously tests the feasibility of the thermodynamic network and its individual elements in relation to external constraints (the validity of the information about expected boundary conditions) and the viability in relation to internal constraints (the validity of the information about the making and controlling of structural types used for expressing functions). If we admit that the semiotic process is about checking and preserving the meaning of an information space used to make it possible the reproduction of the process, then we have to admit the in this process "meaning" – like the meaning we assign to words – is not associated with any physical observable element! As already noted, this is a statement that modern science accepts with difficulties: there are "entities" – like the meaning of letter strings – that are "real" even if they are not material. For example there is the meaning of the English word "dog" that is the same of the French word "chien" and the Spanish word "perro" and the Italian word "cane". Put in another way, if all the observers perceiving the characteristics of a dog can agree on the usefulness and the validity of the meaning associated to such a label – the word "dog" in English - we can infer that there is something "real" out there is responsible for this convergence. *'**Such a "real" thing obviously is not an organism belonging to the species canis familiaris**. In fact organisms can only generate local patterns in data-stream (those recognized by a few observers) on a very limited space-time domain. In order to generate coherence across languages we must deal with an equivalence class of physical objects sharing the same pattern of organization and expressing similar behaviors on a quite large space-time domain.*

This class must exist and interact with several populations of non-equivalent observers to make possible the convergence of on the use of a set of meaningful labels in a language. It is the shared meaning of different words in different language that makes it possible to organize them in a dictionary'. (Giampietro 2003, Chapter 2).

This something "real" is the shared meaning that we can consider as the "essence" of "dogginess". The words dog, chien, perro, cane, etc. are the different "names" used for indicating it. The existence of such an essence can only be confirmed by the observation of the existence of specific instances belonging to the equivalence class (dogs) associated with it. In a process in which dogs are reproduced as an equivalence class and dogs are observed and talked about by people using different languages it becomes possible to share the meaning of a given label used to indicate the existence of this essence, even when the labels used for this purpose are different. This example explains why "meaning" can only be handled within a semiotic process, a process in which the usefulness of the information carried out by a formal statement can only be checked in a pragmatic step (using it to guide action). If we accept this point, then we have to agree that life is about the systemic generation of a situation in which it is possible to assign meaning to encoded information in relation to physical processes organized over structural and functional typologies. The difficulty faced by those trying to study life from within the paradigm of reductionism is that they want to deal with this analysis in terms of mechanisms – observable patterns associated with the functioning of physical entities at a given scale. For this reason they do not want to accept the obvious fact that "giraffes have long necks *in order to* eat leave on the high branches of the trees". Going back to the quote of Pattee, we can say that life is established when *there is an integrated set of processes capable of assigning, validating and using the meaning of formal representations of a set of functional and structural types used in a process of autopoiesis (informed autocatalytic loops using information to stabilize themselves) operating across different scales*. Eliminating the jargon we can rephrase this definition as: *life is about preserving the meaning of interacting essences that are perceived and represented in different ways by non-equivalent agents*. When reading the previous sentences this seems a quite scaring definition. However, in the rest of this essay I hope that after introducing a set of new narratives and theoretical concepts associated with life, the reader will be able to recognize that this complicated description refers to the most natural and familiar process taking place in this planet . . .

1.4 The content of the rest of this essay: disclaimer and apologies

This introduction can be summarized by saying that the huge success of molecular biology in the 60s muddled for a while the discussion over life and evolution. In fact, the mechanism of DNA replication provided an explanation for both the stability of life forms (the replication using a code) and the variability driving evolution (the mutations due to errors in replication). The simplistic mono-scale explanation given by molecular biology was quite weak but it was the best available. Above all it was consistent with the strategy of reductionism: (i) it is obtained by looking and exploring the external world on the bottom; and (ii) the explanation is given by looking at mechanisms (no immaterial entities are involved!). However, in the last 50 years many scientists, operating in different fields, have been working on the development of innovative narratives providing additional and alternative explanations about the existence of life. They proved that it is useful to do explorations also at the top. As result of this extraordinary work carried out by so many people, it would be possible today to adopt a more robust and richer theoretical framework in relation to the question "what is life"? This is what convinced me to dare to propose a sort of brain storming about the possibility of generating a new version of the original paper of Schrödinger by standing on the shoulders of many giants that have paved the road to such an update: (i) Prigogine and his co-workers (Prigogine, 1961; Glansdorf and Prigogine, 1971; Nicolis and Prigogine, 1977; Prigogine, 1978; Prigogine and Stengers, 1984) developing the concept of dissipative systems in the new branch of non-equilibrium thermodynamics; (ii) Maturana and Varela proposing the concept of autopoietic systems

(systems that make them-selves) implemented in different terms in theoretical ecology by H.T. Odum with the analysis of the metabolic pattern of ecosystems *producing themselves through informed autocatalytic loops*; (iii) von Uexküll's work on Bio-Semiotics complemented by the epistemological analysis of Pattee on the limits of reductionism when dealing with the analysis of life; (iv) Herbert Simon laying the basis of complexity theory and the superb analysis of anticipatory systems and their modeling relations of Robert Rosen; (v) Kauffman exploring in details the possible mechanisms of self-organization generating order and in particular the ability of Bolean networks to establish communications. In the same line of research the work of Morowicz and Heigen looking at the characteristics of self-organization determining the complexity of thermodynamic networks; (vi) Koestler that introduced the concept of holons and holarchies and the implementation of this concept in theoretical ecology by Timothy F. Allen, Salthe and many others; (vii) Robert Ulanowics with his seminal work on theoretical ecology, looking for emergent properties of ecosystems not associated with the characteristics of individual organisms (centripetality and the existence of teleology in ecosystems when life is analyzed at the level of the whole system); (viii) C.S. Holling adaptive cycles provide a logical tool useful for analyzing the resulting evolutionary patterns across multiple scales, especially when combining this concept with the concept of holons; (ix) Taleb has recently provided the last piece of the puzzle – the concept of optionality – explaining how it is possible for life "to win" also when playing a game in which decisions have to be taken in face of uncertainty. That is, in a situation of radical openness (a necessary characteristic of life to get adaptability) it is impossible to get reliable predictions, yet it is still possible to stabilize the interaction of complex adaptive systems driven by anticipatory systems using optionality. When living systems win, they win a fortune (new useful types), when they lose they lose very little (just instances of an existing type backed up by redundancy); and finally (x) Barbieri introducing the concept of codepoiesis - the ability of establishing relations among domains completely unrelated in terms of scale and dimensions that are used in autopoietic processes. This ability, typical of codes, makes it possible to establish the required bridges between information and thermodynamic processes operating across different scales. Therefore, codepoiesis is at the basis of a key characteristic of complex autopoietic system - radical openness - needed to generate continuously emergent properties.

In the rest of this essay I try to combine the work of all these people to generate an updated discussion about "what is life" by continuing on the direction indicated by Schrödinger. Because of this choice, I have to start with two apologies to the reader:

(i) *genuine trans-disciplinary work is difficult to sell* - since several innovative theoretical concepts have to be combined and since these concepts are not familiar to the majority of the readers, it is necessary first of all to introduce, explain and illustrate them with practical examples. For personal experience I know that readers are bothered when forced to handle a lot of unfamiliar narratives taken from unfamiliar disciplinary fields. Unfortunately, this is what is done in the next pages of this essay. Even though I try to use simple and self-explanatory examples providing useful insights for the analysis of complex systems, next sections provide a lot of information to digest!

(ii) *nobody can be a reputable scholar in many different fields* - when presenting the material in the next section, there are cases in which I have a reasonable knowledge of what I am talking about, in other cases I am just recycling pieces of information and insights that I found useful for generating a coherent theory and explanations about what is life. In relation to this choice, I can only recycle the apology written by Schrödinger (1944) at the moment of the writing of the "what is life 1.0". I believe that it cannot be said better than that. "*A scientist is supposed to have a complete and thorough knowledge, at first hand, of some subjects and, therefore, is usually expected not to write on any topic of which he is not a life master. This is regarded as a matter of noblesse oblige. For the present purpose I beg to renounce the noblesse, if any, and to be the freed of the ensuing obligation. My excuse is as follows: We have inherited from our forefathers the keen longing for unified, all-embracing knowledge. The very name given to the highest institutions of learning reminds us, that from antiquity to and throughout many centuries the universal aspect has been the only one to be given full credit. But the spread, both in and width and depth, of the multifarious branches of knowledge by during the last hundred odd years has confronted us with a queer dilemma. We feel clearly that we are only now beginning to acquire reliable material for welding together the sum total of all that is known into a whole; but, on the other hand, it has become next to impossible for* *a single mind fully to command more than a small specialized portion of it**. I can see no other escape from this dilemma (lest our true who aim be lost forever) than that some of us should venture to embark on a synthesis of facts and theories, albeit with second-hand and incomplete knowledge of some of them -and at the risk of making fools of ourselves***".

Moreover, since the writing of his piece in 1944 the amount and the pace of scientific research literally exploded, putting modern scientists willing to integrate different items of disciplinary knowledge developed in different fields relevant for a given complex issue in a much more difficult situation that the one experience by Schrödinger then. On the other hand, there is no other way than trying to do so. I firmly believe that we should start exploring and using as much as possible all the information space available for discussing life, if we want to get a better understanding. The ultimate goal is to find and combine useful narratives found not only "on the bottom" but also "on the top" of the systems we are observing. Moreover, it is essential that we learn how to include ourselves among the things to be observed: life is about reflexivity even when there is no personal consciousness. The meaning of life is about the making of the "selves", even if many of the systems generating this meaning do not have consciousness. As a matter of fact, the problem with understanding this meaning is only experienced by those having consciousness. In fact, only humans struggle when trying to understand who is "us" in the stories used in their semiotic processes. The rest of the text is organized in two parts:

PART 1 – The natural existence of purposes, beliefs, and the possibility of learning

2. "what is life?": the unfinished revolution of non-equilibrium thermodynamics

In 1944 Schrödinger proposed a truly revolutionary piece whose consequences were never fully appreciated neither by those working in biology or in thermodynamics;

3. The implications of Autopoiesis and Biosemiotics: generating the possibility of learning

It is only when you have purposes, beliefs and semiotic controls determining predictable patterns that it becomes possible a process of learning.

4. The feature of grammars making it possible to get a semantic closure

The semantic closure over a semiotic process can only be obtained when the meaning of a formal statement is checked against its ability to guide action. The semantic closure of a semiotic process comes when the information has been proved "useful" to preserve the identity of the autopoietic system using it. In turn this requires the simultaneous establishment of two integrated processes using information at two different scales. This is why grammars are needed to handle this task.

PART 2 – The handling of the semantic step (TRANSDUCE) in the semiotic process

5. Koestler "Holons and Holarchies": the ignored revolution of hierarchy theory

The epistemological implications of the unavoidable co-existence of multiple scales – a key issue when studying complex systems - was never considered seriously in mainstream science (and it shows!).

6. The "naming of the Tao" in the semiotic process: the endless dance between thermodynamic constraints and useful information across scales

This dance done by informed autocatalytic loops of energy flows is orchestrated by the establishment of a metabolic Sudoku.

7. The taming of uncertainty or "how to win when using bad models": the concept of optionality suggested by Taleb

A holonic organization of the semiotic process makes it possible to achieve optionality. In the continuous process of becoming of life, IF an innovation generates a better solution in terms of structural and

functional types, THEN it can be amplified across scales. On the contrary, IF an innovation generates a defective copy of a functioning structural type, THEN the loss is limited to that instance.
Conclusion – so what? What is life? Did we gain any insight from all of the above?
Codepoiesis is what makes life unpredictable and possible in the first place

PART 1 – The existence of purposes, beliefs, and the possibility of learning

2. Schrödinger "what is life? (1.0)": the unfinished revolution of non-equilibrium thermodynamics

2.1 The negative entropy revolution
In 1944 with his seminal work "what is life?" Schrödinger dropped the bomb of an epistemological revolution associated with the concept of non-equilibrium thermodynamics that is "the" key conceptualization for any discussion of life. However, his truly revolutionary piece was never appreciated in relation to its deep implications, not in physics, nor in thermodynamics or in biology. Probably the reason for this fact is that everybody was looking at the bottom . . .
In order to stress the special status of living systems Schrödinger - one of the most reputable physicists of his time! – "invented" a scientific non-sense, "flows of negative entropy", to describe what is that makes it possible life. In fact, it should be noted that in the grand narrative of classic thermodynamics - determining the existence of inexorable laws and the direction of time - flows of entropy can only be positive! For this reason he was judged wrong by his orthodox colleagues and forced to correct the politically incorrect statement later on in his life. But what was he trying to say? Obviously, he was trying to flag the need of going for "something completely different" capable of explaining the co-existence of a double mechanism of self-organization (a combination of order from order and order from disorder) operating across different scales. Order from disorder arises when positive feedbacks encounter a negative feedback constraint. The when that arrangement is codified for stability, order from order (e.g. codes associated with genes) becomes a possibility.
The idea proposed by Schrödinger has been later on elaborated by Prigogine and colleagues (Prigogine, 1961; Glansdorf and Prigogine, 1971; Nicolis and Prigogine, 1977; Prigogine, 1978; Prigogine and Stengers, 1984) when introducing the class of dissipative systems with the development of the field of non-equilibrium thermodynamics. Dissipative systems exchange matter and energy with their environment on which they depend in order to be able to establish their structures and express their functions. The main point relevant for the discussion about life is that living systems have an identity which imposes on them a given, specific internal perspective on the external world. In order to make this point, Schrödinger introduced the controversial narrative of living systems feeding on "negentropy", where the definition of negentropy must be specific for different typologies of living systems. As already mentioned the concept of entropy in classic thermodynamics is associated with situations of equilibrium where it is possible to define a state space – i.e. a finite set of relevant observables for known typologies of thermodynamic processes for which we assume that it is possible to obtain reliable measurements. Therefore the conventional interpretation of the concept of entropy applies to known "typologies" of thermodynamic transformations in which the special characteristics of the instances are totally irrelevant. Put it in another way, if we develop a system of representations of thermodynamic transformations based on standard typologies – e.g. perfect gas – this representation is too generic to be applied to the analysis of biological metabolic

systems – e.g. antelopes and lions. As Fermi stated correctly, classic thermodynamics "is mainly concerned with the transformations of heat into mechanical work and the opposite transformations of mechanical work into heat" (Fermi 1956, p.ix). Living systems do not belong there. The quantitative analysis developed in classic thermodynamics requires a pre-analytical definition of a closed information space defining a given set of possible energy forms and a given set of transformations to be considered. The standards typologies of energy conversions studied in classic thermodynamics must apply in the same way to virus, plants, herbivores and carnivores. The problem with this choice is that the definition of "energy" within this narrative is absolutely generic. Poincaré rightly observed that "in *each particular case* it is clearly seen what energy is and at least a provisional definition of it can be given; but it is impossible to find a general definition for it. There only remains for us one enunciation of the principle of the conservation of energy: There is something which remains constant. *Under this form, it is in its turn out of the reach of experiment and reduces to a sort of tautology*" (italics added, Poincaré, 1913, p. 121). Lotka in his *Elements of Mathematical Biology* expresses a similar concern for the limitations of the generic representations provided by classical thermodynamics: "*the very fact that they [the laws of thermodynamics] hold independently of substance and form lends their application a catholicity hardly equaled elsewhere in science, and at the same time gives into our hands an instrument of the most extreme economy of thought, since we are relieved, in such application of the necessity of treating each particular case, with all its complication of details, on its own merits, but can deal with it by the shortcut of a general formula. Still, the austere virtue of this impartiality [of the second law of thermodynamics] with respect to substance and form, becomes something of a vice when information is sought regarding certain systems in which mechanism plays, not an incident, but the leading role. Here thermodynamics may be found powerless to assist us greatly and the need for new methods may be felt*" (Lotka, 1956, p. 327). What is an energy input for herbivores is different from what is an energy input for viruses or carnivores. Therefore, when dealing with the analysis of energy conversions in living systems we have to abandon one of the main ideological assumptions of reductionism: the possibility of defining a substantive representation of event which is "the same" for different observers and agents operating in different dimensions and scales. This is exactly the revolution introduced by non-equilibrium thermodynamics and suggested by Schrödinger. A given definition of "entropic flow" can be perceived as either good or bad depending on the perspective (or pre-analytical narrative) adopted for the analysis. The perspective is given by the identity of the living system. As a matter of fact, when discussing in very general terms the basic feature of living systems, he suggests that the question to be answered is: "how does the living organism avoid decay?" "*The obvious answer is: by eating, drinking, breathing and (in the case of plants) assimilating. The technical term is metabolism. The Greek word . . . meaning change or exchange*" (Schrödinger, 1944 p. 71). This is idea is reflected in the conceptualization of the class of dissipative systems defined as ***open systems feeding on "negative entropy"*** that they must take from their context. "Negative entropy" is associated with the concept of the food for animals and solar energy for plants (specific forms of exergy on the input side) and with the concept of turnover of materials in the exchange with the environment required to reproduce and operate the structural and functional compartments of dissipative systems.

2.2 The relevance of the concept of negative entropy for the question "what is life"

Under the pressure of orthodox physicists Schrödinger had to reformulate the concept of negentropy in a more conventional way as "the existence of a '**system-specific**' set of favourable boundary conditions determining the possibility for the living system to discharge entropy". However, also in this "politically correct" formulation the revolutionary input of Schrödinger remains valid and it results in two main points:

(1) an operational definition of what should be considered as free-energy (exergy or "a resource") or what should be considered as a threatening form of boundary conditions ("waste") for a living system ***cannot be defined in a "substantive" way***, but it depends on the identity (i.e., the specific characteristics of the metabolic system under study, that have been frozen in time due to path dependency). Living systems generate "system-specific" definitions that generic disciplines such as physics or thermodynamics cannot handle. For example, human excrements are waste for modern humans but at the same time a valuable resource for soil insects. Grass is food and therefore an energy input for herbivores but not for cars;
(2) this conceptualization of the operation of metabolic system implies ***the co-existence of two distinct processes that cannot be reduced to a single representations***: (i) the internal activity of the metabolic system producing "positive entropy" to be disposed into the environment. These processes must be able to reproduce the structure of the system expressing the required functions; (ii) the external activity of processes outside the control of the metabolic system guaranteeing the stability of the boundary conditions of the metabolic system. These processes must make available to the metabolic system the required flow of negative entropy. The overall result of the combination of these two independent processes (inside the metabolic systems and outside the metabolic system) is that metabolic (dissipative) systems can maintain their structural and functional features and reproduce themselves in time.
A generic illustration of the conditions making possible the reproduction of dissipative systems is given by the expression below:

$dS_W = dSi + dSe$

where:
* dS_W - the overall generation of entropy of the dissipative system considered as a whole;
* dSi - the rate of production of entropy due to the internal activity of the system, this flow is positive by default;
* dSe - the flow of entropy determined by the interaction with the environment – favorable boundary conditions – this flow must be negative, according to the narrative proposed by Schrödinger. The interaction with the environment has to guarantee to the dissipative system the expected favorable boundary conditions required to sustain or amplify its pattern of entropy generation. That is boundary conditions are favorable when they provide the possibility of producing and discharging more entropy.

Using this relation we can specify the three conditions required for the reproduction and growth of dissipative systems as follows;
(i) the flow of dS_W must result negative (or zero) for the dissipative system
(ii) the sign of dSe must be negative (-dSe) in relation to dSi
(iii) the quantitative value of $|dSe| > |dSi|$.

It should be noted that the relation over these three terms is based on the simultaneous description of events at different levels:
(a) the pattern of dissipation of the whole determined by the combination of the effects of internal processes (controlled by the dissipative system inside the black-box) and external processes (the process outside the control of the dissipative systems determining the stability of favorable boundary conditions) – black-box interacting with the context;
(b) the pattern of dissipation inside the system where entropy is produced in order to express organized structures and functions (the metabolic pattern) – processes inside the black-box;

(c) the pattern of interaction with the context that must be able to absorb the entropy generated by the internal process. This requires that the set of processes not controlled by the dissipative system must be able to express the required "–dSe" – processes outside the black box.

As mentioned earlier, since these processes are taking place simultaneously across different scales it is impossible to generate a coherent quantitative representation when using a single descriptive domain. This may explain why this relation is certainly very useful to conceptualize the stability of dissipative/metabolic system but it is very hard (if not impossible) to implement in formal terms within the classic thermodynamic narrative (Mayumi and Giampietro, 2004). In any case, when trying to answer the question "what is life" this conceptualization can be used to make four important points:

Point #1. the identity of a dissipative system (an established pattern of energy dissipation associated with a set of expected characteristics determined in the past by path dependency) when expressed by a given instance indicates that the three conditions listed above are verified now, and have been verified in the past. This identity is determined by a set of biophysical constraints and by stochastic events determining a path dependence in the definition of the identity. For example a tornado (a typology of dissipative system) is determined by an attractor generating a rotating structure, however, the structure can rotate either clockwise or anti-clockwise. The characteristics of a specific instance of this typology (a tornado rotating clockwise) has been determined by stochastic events that took place at the moment of its formation and are preserved until the specific instance can produce and dissipate entropy. If the instance of tornado "dies" this information about its history is lost. Looking at the mechanism of constraints generating a tornado we can define the expected characteristics of an instance of tornado, but then we cannot know in advance the direction of rotation. This is a characteristic determined by chance (initiating conditions) and preserved in time as a frozen accident in the identity of the instance.

Point #2. The internal mechanism of entropy generation of a dissipative system will determine a predictable pattern in terms of physical processes. Getting back to the example of the tornado, we cannot guess the direction of rotation of a special instance of tornado but we can predict a lot of information about its typology. The same applies to Bénard cells, flames and other examples of dissipative structures.

Point #3 the identity expressed by a dissipative system depends on the simultaneous existence of an attractor determined by physical laws – e.g. the typology of the tornado – and by an additional input of information determined by the history of the system – i.e. the frozen accident amplified and stabilized at the moment of the formation of the tornado. This is the input of information determining its rotation either clockwise or anti-clockwise. In simple dissipative systems this characteristic is not particularly relevant because it just reflects the effect of stochastic events taking place at the moment of the formation of the dissipative systems. However, when dealing with autopoietic dissipative systems, where information is stored and recorded to reproduce the metabolic pattern, this fact becomes crucial. In fact, the identity of the system (what generates the mechanism of entropy generation) is no longer determined only by physical laws and by chance but rather by mechanisms of controls based on the recorded information. We are dealing again with history frozen in the information space, but rather than having just a bit of information (clockwise or anti-clockwise) we have the possibility of preserving and "improving" an important information space that is written in codes. In autopoietic metabolic systems the mechanism of entropy generation is determined by semiotic controls defining constraints reflecting the effect of adjustable rules and not of inexorable laws – Pattee 1995;

Point #4 when dealing with living systems it is impossible to develop in general terms an effective and useful scientific analysis which would provide useful information capable of considering at the same time the point of view of a living systems (the internal view, the characteristics determining "dSi") together with the point of view of its context (the external view the characteristics determining "–dSe"). This point is especially important when dealing with complex systems organized in a cascade of autopoietic processes across different hierarchical levels of organization and scales. Therefore, we must be aware that a

metabolic process when analyzed at a given level of organization always requires the analysis of two non-equivalent views and an assumption about the stability of boundary conditions:
(i) the view from inside the system – needed to describe the energy transformations taking place within the black-box (the ability of expressing power and generating entropy to be exported to the context);
(ii) the view from outside the system – needed to describe the energy transformations associated with the interaction of the black-box (seen as a whole) and its environment;
(iii) assuming that unknown processes will guarantee the stability of favorable boundary conditions for the dissipative system, in spite of its dissipative activity aimed at destroying favorable gradients.

The two views of the process of dissipation are not reducible to each other when coming to their formal representation (they do not have a common descriptive domain) and this explains why the relation proposed by Prigogine to explain the overall balance of entropy production and disposal of a dissipative system is problematic in terms of a quantitative representation with classic equations of thermodynamics (Mayumi and Giampietro, 2004).
The perspective from the inside - the more energy is dissipated, the more power is expressed by the metabolic system the better (Maximum Power principle – Odum and Pinkerton, 1955) has to result compatible with the existing boundary conditions, since the biological system depends on the context that must be able to supply the required flow of negative entropy. When considering the perspective from the outside, it is not wise to be too demanding on the environment (Minimum Entropy Generation principle – Onsager and Machlup, 1953). We can consider this Yin-Yang tension across different views of the dissipative process as a key driver of evolution in life (Giampietro and Mayumi, 2008). The characteristics of processes taking place simultaneously in the two distinct perceptions (internal view and external view) referring to two different scales (non-equivalent descriptive domains) cannot be represented and encoded using a single set of formal symbols. Codes mapping entities or events referring to the internal mechanisms of entropy generation (formal signs mapping onto entities and events associated with "dSi") are necessarily not equivalent to codes mapping external mechanisms generating negative entropy (formal signs mapping onto entities and events associated with "-dSe"). This point is essential for understanding the peculiarity of the semiotic process: the meaning of the information used in a semiotic process can only be checked by looking at the congruence between the various symbols and their specific external referents when applying syntactic rules to formal statements – e.g. reading and transcription of a genetic code. However, IF this congruence has to be checked simultaneously in relation to two non-equivalent views – the internal view and external view - THEN such a double check can only be obtained looking for a semantic closure achieved over a semiotic process over the two non-equivalent sets of encodings. This will be discussed in detail in the next sections.

Thus, according to non-equilibrium thermodynamics the maintenance and reproduction of the identity of a metabolic system implies the ability of reproducing:
(i) at the local scale the identity of a set of mechanisms needed to reproduce the characteristics of a local metabolic pattern "dSi" – it requires recording and transmitting the instructions about how to produce the structural type capable of expressing a set of functions and having the ability of using these instructions to make instances of this structural type;
(ii) at the large scale the identity of the expected set of boundary conditions making the functional type meaningful "-dSe" – it requires the ability of providing the right associative context for the structural type (e.g. the set of inputs required for its metabolic pattern and the sink capacity for absorbing the wastes associated with the functioning of the structural type, plus the possibility to express its expected behavior).
It should be noted that the characteristics determining the processes stabilizing boundary conditions are totally unrelated to the characteristics of the processes determining the internal process of entropy

production. For example, the transcription of the DNA of a dog takes place at a constant temperature, the dog is living in an environment expressing different temperatures;
(iii) ***a mechanism making it possible to establish and maintain the congruence over these two sets of activities expressed at different scales associated with the definition of the same identity "from the inside" and "from the outside"*** . The possibility of synchronizing the two processes needed for stabilizing the meaning of both the structural type (the metabolic pattern expressed by "dSi") and the functional type (the compatibility of boundary conditions with such a pattern guaranteed by "dSe").

In conclusion, non-equilibrium thermodynamics does not say anything about how to stabilize and to reproduce in time dissipative structures, but it makes it possible to conceptualize the implications (expected requirements) of a stable reproduction of complex typologies of metabolic systems. An example of this expected set of relations over the interface "identity of the whole"/ "identity of parts" (the local scale view of the dissipative systems) and the interface "identity of boundary conditions" / "identity of large scale processes generating the boundary conditions" (the large scale view of the associative context of the dissipative systems) is illustrated in Fig. 2.

Fig. 2 Expected relations between: (i) internal view (left) - characteristics of parts/whole; and (ii) external view (right) – characteristics of the negentropy flow/boundary conditions

A horse (the dissipative system) because of its internal mechanisms (associated with its physiology) defines a constant supply of "hay" as one of the key components of its boundary conditions (negative entropy provided by its associative context) required to be stable in time. If we assume that it is possible for the horse to get a constant supply of hay, then we have also to assume that there are processes outside the control of the horse that generate such a supply. In the same way, if we consider a car as the dissipative system of interest, then its internal mechanisms of conversion of exergy input into work (as defined by the nature of the engine), defines a constant supply of "gasoline" as one of the key components of its boundary conditions (negative entropy provided by its associative context) required to stabilize its functionality in time. Also in this case, the constant supply of this flow of gasoline entails the existence of other processes independent from the functioning of the car that guarantee such a supply.

3. The implications of Autopoiesis and Biosemiotics: *generating the possibility of learning*

Four elements are required in order to have a process of learning: "purposes", "beliefs", "semiotic controls" (determining the possibility to observe, produce and model expected patterns) and a "criterion of truth" the concepts of Autopoiesis and Biosemiotics explain how these four elements are present in living systems.

3.1 Autopoiesis and semantic closure: the final secularization of teleology

Maturana and Varela (1980, 1998) put forward the concept of autopoiesis as a peculiar characteristic of living systems. Autopoiesis literally means self-production (in Greek *poiesis* means creation or production) and it expresses a special characteristic of dissipative systems in which structures and functions are deeply related to each other***.***

"*Autopoiesis is a term for the "self-defining", "circular" organization (organizationally closed but structurally, i.e., materially and energetically, open) of a living system (such as a cell), consisting of a network of component metabolites that produces the very network and its own components plus the boundary of this network.*" (Emmeche, 1997)

"An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network." (Maturana and Varela, 1973, p. 78)

A similar concept has been introduced by Robert Rosen (1985; 1991) when describing living systems as M-R systems (Metabolic-Repair systems) that are "closed to efficient cause". This expression implies that these systems are able to reproduce and repair themselves throughout their metabolic activity and that they contain models of themselves making it possible to be their own makers. Finally, H.T. Odum (1971; 1983) described the processes capable of reproducing ecosystems as "informed autocatalytic loops".

All these concepts moving around the basic rationale of autopoiesis are very relevant for the theoretical discussion about "what is life" because they imply a total secularization of teleology. In fact, an autopoietic system ***by definition has the purpose of remaining alive and reproducing itself***. Therefore the information used in a process of autopoiesis is associated by default with the goal of reproducing itself. Moreover, as discussed before, if we assume that an autopoietic system can reproduce itself because of recorded information about "how to reproduce its expected metabolic pattern" (determining the ability of producing a given pattern of entropy dSi), we can imagine this information ***as representing a belief about the possibility of finding favourable boundary conditions*** – the expected associative context – in which to express such a metabolic pattern. The concept of autopoiesis does not address the question "who made the autopoietic system", but after accepting the existence of this class of systems (Maturana and Varela, 1980, 1998; Kampis, 1991) we can assume that by default they have: (i) a purpose; and (ii) a belief about the associative context. Therefore, when dealing with the analysis of these systems one no longer needs to assume the existence of God to explain that complex autopoietic systems have telos!

Another important aspect of the concept of autopoiesis is that it entails a fundamental complementarity between "structural types" and "functional types" found in biological systems. A living system is a realization of a holon – i.e. a successful coupling of a structural type, defined as a metabolic pattern expressing behavior at the local scale, and a functional type, defined as the meaning assigned to the "local scale behavior" when looking at the emergent property that this behavior makes possible at the larger level. In metabolic system this emergent behavior requires the existence of a set of favorable boundary conditions stabilized by unknown processes at a larger scale. Therefore, when considering an established holon that is reproduced using recorded information it is possible to say that the structural type has the goal of expressing the coupled functional type without implying that God decided this way. Living systems are different from other simple mechanical systems. Mechanical systems are produced by design, therefore they require an external maker that has also to assign them a goal (functional type). Mechanical systems are not capable of checking the meaning of their organization. That is, non-autopoietic systems require both an external agency and an external definition of purpose. On the contrary autopietic systems must be able to provide both inputs (agency and purpose/belief) by themselves. For example a microorganism depends on favorable boundary conditions (it must verify the validity of its belief about the existence of "-dSe"), but then in the case the belief is verified, it can reproduce itself autonomously. On the contrary a car is an allopoietic system, since it needs not only an adequate flow of inputs (the flow "-dSe so to speak) but also a designer and a maker knowing how to produce it.

Learning is another essential feature of living systems, because without learning you do not have the possibility to adapt to becoming boundary conditions. In order to explain the ability of learning expressed by living systems we need to consider two additional key characteristics expressed by them. These two characteristics have been discussed at length in the work of Pattee in relation to the concept of semantic closure. Semantic closure is the process making it possible for life to add "meaning" to "matter". This result is obtained by a continuous commuting between production/use of information and physical processes validating the definition of "usefulness" of the grammars (taxonomies, dictionaries and systems of codes) used to guide action in this commuting. The basic rational of this process of commuting has been indicated by Simon (1962) - life is a process of resonance between making recipes used for making processes used for making recipes - and by Prigogine (1980) - life is using DNA for expressing a metabolism that is reproducing the DNA used for expressing metabolism. This commuting is a necessity if one wants to preserve the memory of the experience made in past interaction with the external world in the form of recorded information. In fact the records of information must have a material basis to be preserved. However, it is impossible to preserve meaningful information by recording it on a material medium for two reasons: (i) no matter how robust is the material used for keeping such a record it is impossible to guarantee that over the very long period (e.g. thousands of year) a given record could be preserved in its full integrity; (ii) after accepting that complex adaptive systems – i.e. living systems – must be "becoming systems" a piece of information recorded on a physical medium outside its original context will become obsolete if its meaning is not continuously updated in time. For this reason, the only way to preserve useful information about an experience is via a process of resonance between recorded information coding its own reproduction after going through a "reality check" in the external world. The reality check guarantees that the original meaning has been preserved.

Due to the possibility of changes in boundary conditions, autopoietic systems have to learn how to update their memories about past interaction with the external world. This implies that the records have to be update by eliminating obsolete information, adding new useful information and preserving the information that proved to be still valid. Moreover, the same information can result either meaningful or meaningless in different contexts at a given point in time. For this reason in the process of continuous validation of the meaning associated with a given recorded information it is essential to operate with a certain level of redundancy in the information space. This explains the use of equivalence classes of instances of a given living system used for reproducing the recorded information referring to a local space-time domain – e.g. how to make an organelle or how to make an organism - on a large space-time domain – e.g. the domain of activity of all living systems sharing that organelle or the domain of activity of the species to which the organism belongs. By learning new meanings and by updating their memory about their past interactions with the external world living systems must become something else, during their evolution. This fact generates an apparent paradox: living systems must change in order to remain themselves! This is another paradox (discussed in Section 3.4) that shows the importance of using semantics (and not syntax) when dealing with the characterization of the identity of living systems.

The tension between the use of a syntactic versus a semantic definition of identities when dealing with the study of life has been very well explained by Rosen (1972). In general reductionism tends to "abstract away the organizational properties of the system leaving behind a purely structural residues" – i.e. the focus is on the characteristics of the structural type of the holon or even worse of the material characteristics of instances of the structural type. On the contrary according to Rosen "what we shall do, in effect, is to begin by abstracting away the structure (that is, the physics and the chemistry) of the system, leaving behind only the functional organization" – i.e. the focus should be on the characteristics of the holon in relation to the functions it expresses in its context. Another famous quote of Rosen (reported by his daughter) is about the turnover of the material components of the human body. In a couple of months the vast majority of the material particles of the human body is changed, still we can talk of an individuality of a human being, that remains the same over a much larger time window. This fact clearly suggests that an individual human being can keep its memory and its individuality because of a set of relations between the functional components (realized by instances made up by material particles). This identity is independent from the specific identity of instances of lower level material components. An example of this fact is discussed in Part 2 when discussing the concept of centripetality in ecology.

Within this line of reasoning Pattee has proposed the concept of semantic closure in a semiotic process to flag the impossibility of describing in syntactic terms the process of autopoiesis. It is a semantic check that makes it possible the closure of efficient causality. To support my argument, I introduce two essential points made by Pattee:

1. the semantic closure requires the convergence of the meaning of two logically independent process of coding and decoding that are taking place simultaneously at two different hierarchical levels of organization and two different scales.

"I have argued that the simplest context that would allow the normal use of epistemic concepts like measurement and observer **is an organization that can *construct* the measuring device and use the results for its survival**. In other words, measurement is not distinguishable by the local behavior of any mechanism. **To qualify as a measuring device it must have a *function*, and the most primitive concept of function implies improving fitness of an organism**. **Thus, *observation and measurement require an organization that (1) constructs the measuring device and (2) uses the results of the measurements for survival*.** This requirement I have called the *semantic closure principle* (Pattee, 1982; 1995). This provides an objective criterion for distinguishing measurements and observations from other physical interactions. Only organizations with this semantic closure property should be called *observers"*. Pattee (1996)

In this example the scale at which the measuring devices is constructed and operated (where we have a first check of the validity of the code used there for measuring) is different from the scale at which the usefulness of the measures for guiding action is checked (where a second check on the validity of the encoded information when used for guiding behavior). In fact, the survival of the organism and its ability of reproducing (including the local fabrication and use of measuring devices) is associated with the successful result of the two actions taking place simultaneously at two scales. The large scale action is based on the information gathered by the operation of observation and measuring, a local scale action, used as an input for the operation of anticipatory models for guiding action. This double convergence of meaning will be discussed with a practical example of the role of grammars in getting a semantic closure in Section 3.4.

2. the semantic closure requires the existence of patterns that are predictable. They must be both recognized – when interacting "with the other" - and produced - when reproducing "the self". To achieve this result they must be generated by semiotic controls. This guarantees that the predictable patterns are not determined only by biophysical laws but also by cybernetic controls having contingency.

For example the behavior of a flame is determined by the characteristics of an attractor regulated by physical laws, whereas the behavior of a member of a species of Toucan is determined by the characteristics of its semiotic controls. These controls are reflecting the information (memory) accumulated by the species (the essence associated with the populations of it) in the past interaction with the external world. This explain why if we want to predict the behavior of a flame we can use equations based on physical laws to predict the characteristics of the type (flame), whereas if we want to predict the behavior of a Toucan we have to use not only our knowledge of aerodynamics but also our knowledge of its semiotic controls. . .

Put in another way, the constraints determining the metabolic pattern and the behavior of living systems are generated not only by the existence of physical laws but also by the recorded information reflecting the memory of the interaction of the "essence" of the specific living system with the external world. This part that is special for different types of living systems is what Pattee calls "semiotic control". These semiotic controls must obey the physical laws but are not determined or predictable by these laws. At the moment of their reproduction living systems use their own semiotic controls (the memory of the essence to which they belong) for reproducing and for learning: living systems generate internally their own constraints determining their own metabolic pattern and behavior. As noted earlier, the preservation of this memory (e.g. the records of information about the essence of a species) implies the establishment of a process – a set of energy transformations – validating the usefulness of the recorded information. The success in establishing the physical process of reproduction confirms the validity of the information used for controlling the process. In life the definition of an "essence" is associated with the successful establishment of an equivalence class of metabolic elements (instances of types) that express predictable patterns that "makes sense" (they have meaning) in relation to the processes determining the larger context. The pattern makes sense in relation to the goal of its reproduction when the characteristics of the metabolic pattern of an instance of the equivalence class can be known and coded simultaneously: (i) from the inside, developing information (a family of codes) about how to make new instance of this class; and (ii) from the outside, developing information (a family of codes) about how to interact with instances of this class (either using them as food or avoiding them as potential threat). In this situation the amount of recorded information making up the memory of the "essence" is preserved and tested by the turnover of instances produced in equivalence classes. In turn this turnover makes it possible the phenomenon of learning. In fact, the essence can update his memory by a series of selective changes to the existing records used to express semiotic controls. Again it is important to recall that the records are not in any material structure, but in the semiotic process itself taking place across scales at a very large space-time.

In conclusion when integrating the analysis of Pattee in the concept of autopoiesis and negentropy discussed before, we can see that all the ingredients required for having the phenomenon of "learning" are present in living systems: (i) Autopoiesis → Purpose; (ii)
Negentropy → Beliefs; (iii) Semiotic control → Contingency (the existence of an option space in the recorded information that can be changed); (iv) Semantic Closure → Local criterion for truth

3.2 Biosemiotics and the learning of autopoietic systems

Before introducing the concept of Biosemiotics we can just recall the basic concept of the Semiotic triad proposed by Peirce. In order to have a semiotic process of interpretation you must have three elements:

(1) a "representamen" (R) *– this is* ***material*** *observed entity to which meaning is assigned (it signifies something to someone);*
(2) the "signified" (X) *– this is the external referent giving the meaning to the signifier. As noted earlier, this can be a type and not necessarily a material object;*
(3): an "interpretant" (I) – *this is a process capable of establishing a semantic connection between R (sign) and X (the external referent giving meaning to the sign). The interpretant can do so by perceiving such a connection within a given associative context.*

In relation to the semiotic triad we can distinguish three domains useful to study the operation of a process generating a semiotic closure (I am taking this from "semiotics for beginners", Chandler):

** Semantics: the meaning of signs (the relationship of signs to what they stand for).*
** Syntax: the relations between signs (without regard to meaning).*

** Pragmatics: the ways in which signs are used and interpreted*.

The combination of activities referring to these three domains make it possible to generate what is called a semiotic process capable of checking the validity of information used for a given purposes (a practical example is discussed in the next section). However, it essential to observe that in life (natural selection!) one has to establish several processes of coding (encoding and decoding) that are operating simultaneously across different scales in order to achieve a semantic closure. In particular: (i) there is a local scale level at which genetic codes are reproduced, read, interpreted and used to produce instances of organisms associated with a given species. This level is essential to generate predictable patterns that can be expected and reproduced in terms of typologies; (ii) there is a large scale level at which the populations of the various species express an integrated set of behaviors making it possible the stabilization of the ecosystems to which they belong. This level is essential to generate the boundary conditions required in order to be able to express the patterns associated with the typologies defined by the information stored at the lower level.

The field of semiotics is in general considered by the general public as a field studying a special feature expressed by the human mind. However, the field of biosemiotics has been exactly established to explore the validity of these concepts outside the domain of social sciences. In fact, the field of biosemiotics was established following the pioneering book of "Von Uexküll (1992, originally published in German in 1934) in which he proposed a theory of meaning, applied also to non-humans. The term Biosemiotics combines the two Greek words: (i) bios = life; and (ii) semion = sign
More information at URL: http://www.ento.vt.edu/~sharov/biosem/geninfo.html from where I got the following definition and brief history of the relative field:

"***Biosemiotics** is an interdisciplinary science that studies communication and signification in living systems. Communication is the essential characteristic of life. An organism is a message to future generations that specifies how to survive and reproduce. Any autocatalytic system transfers information (i.e. initial conditions) to its progeny so that daughter systems will eventually reach the same state as their parent. Self-reproducing systems have a semantic closure (Pattee 1995) because they define themselves in their progeny. A sign (defined in a broadest sense) is an object that is a part of some self-reproducing system*".

Von Uexküll (1940) developed a theory of meaning which considered animals as interpreters of their environment. He called this subjectively interpreted environment Umwelt ('Umwelt' means 'environment' in German). The term "biosemiotic" was first used by F.S.Rothschild in 1962. For a short history of biosemiotics, see the paper of K. Kull" (1999).
As discussed earlier, if we agree that autopoiesis is based on recorded information about how to make instances of a type of organism (e.g. genes), then we can imagine that the information about the making of the organism is an expression of belief about the existence of favorable boundary conditions. Put in another way, we can imagine that a species producing offspring is sending out probes (instances of organisms of the species) into its environment checking the existence of its expected associative context checking in this way the validity of its beliefs. Whenever the information recorded in these probes come back to the species, even better if amplified, it means that the explored environment does provide favorable boundary conditions for the reproduction of instances of that species. Therefore, the successful reproduction of an organism is a confirmation of a belief about the existence of its expected associative context. The sematic closure is obtained and this proofs that the information used in the process is still meaningful.

The description of how the "umwelt" of a tick can be interpreted as a series of "beliefs" about an expected associative context is given in Box 1 using the description made by Von Uexküll himself in its seminal book.

******************* BOX 3.1 – the UMWELT of the tick *********************

"The tick though not dangerous, is still an unpleasant guest of mammals, including men. Recent publications have clarified many details of its life story so that we are able to trace an almost complete picture of it.

From the egg there issues for a small animal, not yet full developed, for it lacks a pair of legs and sex organs. In this state it is already capable of attacking cold-blooded animals, such as lizards, whom it way-lays as it sits on the tip of a blade of grass. After shedding its skin several times, it acquires the missing organs, mates, and starts its hunt for warm-blooded animals.

After mating, the female climbs on the tip of a twig on some bush. There she clings at such a height that she can drop upon small mammals that may run under her, or be brushed off by larger animals.

The eyeless tick is directed to this watchtower by a general photosensitivity of her skin. The approaching prey is revealed to the blind and deaf highway woman by her sense of smell. The odor of butyric acid, that emanates from the skin glands of all mammals, acts on the tick as a signal to leave her watchtower and hurl herself downwards. If, in so doing, she lands on something warm – a fine sense of temperature betrays this to her – she has reached her prey, the warm-blooded creature. It only remains for her to find a hairless spot. There she burrows deep into the skin of her prey, and slowly pumps herself full of warm blood.

Experiments with artificial membranes and fluids other than blood have proved that the tick lacks all sense of taste. Once the membrane is perforated, she will drink any fluid of the right temperature.

If after the stimulus of butyric acid has functioned, the tick falls upon something cold, she has missed her prey and must again climb to her watchtower.

The tick abundant blood repast is also her last meal. Now there is nothing left for her to do but drop to earth, lay her eggs and die". Von Uexküll, (1934/1957) pag. 6-7

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The bridge between information theory and thermodynamic constraints is illustrated in Fig. 3.

Figure 3 The representation of the relation of the three components of the holon-tick: (i) the instance (on the top); (ii) the definition of the structural type (associated with the genetic information); (iii) the definition of the functional type (determined by the thermodynamic constraints associated with the boundary conditions) according to Timothy Allen

Within the scheme provided in **Fig. 3**, the definition of internal constraints depends on the definition of the structural type of the tick (determined by genetic information), whereas the definition of external constraints (e.g. available energy gradients) and more in general the option space for functional types depends on the characteristics of the associative context actually experienced by instances of the structural types operating in the external world.

The concept of biosemiotics has a key importance in the discussion of life because it clearly indicates that even in biological systems, where human intelligence and reflexivity is not present, purpose and beliefs determining semiotic controls are as important as material constraints to determine the feasibility of patterns of behavior. This means that the behavior of any living system (not only of humans) is not determined by biophysical processes, but also by factors associated with meanings and beliefs, which are needed for the establishment of a semiotic process. A fish expects a "reality" made of water, a horse a "reality" made of green prayers. Each organism has a specific perspective about its "own reality" and it has developed within it anticipatory models. For example, cockroaches associate light with danger and run for shadow to save their live. That is, when dealing with living organisms the goals, the taboos recorded in the knowledge associated with a given species are also associated with a particular realization of an observer and an agent. Looking at Fig. 3 we see that the three elements required for operating a semiotic complex: (i) the process recording and transmitting the information about the structural type; (ii) the process generating the external thermodynamic constraints making meaningful the structural type as a potential agent; and (iii) the process associated with the recorded knowledge about ticks – the making and the operation of an instance of tick - that is used to check the semantic closure. Therefore, the semantic closure require the simultaneous existence of different processes operating in the "external world" operating across different scales: metabolic processes within individual organisms of tick, agency of populations of ticks, reproduction of ecosystems within which ticks are operating. Even though this complex multi-scale process cannot be defined in syntactic terms, this process makes it possible to validate the information used by the autopoietic system in a quite easy way. Assuming that the various instances of this holarchy (a chain of holons embedded in each other) made up by: (i) parts of the tick organism; (ii) individual organisms of tick; (iii) populations of ticks; (iv) ecosystems including ticks; (v) biomes made of ecosystems including ticks; are reproduced, then the semantic closure is verified across all the levels. If the population made of a given type of organisms survives, then both the knowledge associated with the expected "relevant reality" (the story telling about the relative niche) and the features of observation and agency are coherent with each other: the biosemiotic complex is able to get the semantic closure on the information it uses for guiding its actions.

Biosemiotics tells us that different organisms are living in different "realities" whose perceptions and representations are incoherent with each other. A dog, a whale, a tick, a tapeworm, and a virus are obtaining semantic closures over their semiotic processes using totally different definitions of "external world" and totally different representations, even though they refers to the same set of sources of potential signals that we can call "the external world". So we can reframe a famous expression of Robert Rosen (2000) by saying that "life is the interaction of semiotic complexes based on non-equivalent story-telling" (the original line was "life is interaction of non-equivalent observers"). In relation to this point, biosemiotics represents a serious challenge to the simplistic perception of reductionism. Robert Rosen starts his book entitled "Anticipatory Systems" (1985) with the following intriguing sentence: "*Strictly speaking, an anticipatory system is one in which present change of state depends upon future circumstances, rather than merely on the present or the past. As such, anticipation has routinely been excluded from any kind of systematic study, on the ground that it violates the causal foundation on which all of theoretical science must rest, and on the grounds that it introduces a telic element which is scientifically unacceptable. Nevertheless, biology is replete with situation in which organisms can generate and maintain internal predictive models of themselves and their environment, and utilize the predictions of these models about the future for purposes of control in the present. Many of the unique properties of organisms can really be understood only if these internal models are taken into account. Thus, the concept of a system with an internal predictive model seemed to offer a way to study anticipatory systems in a scientifically rigorous way*" (Rosen, 1985 pag.***v***).

There are two points that deserve attention in this passage.

 # 1 - in a living system what is affecting present changes - through the operation of a system of control - is not a ***substantive future***, but a ***virtual future*** predicted by a model (a ***belief***). Whenever the agent survives "the virtual future" used in the system of controls (***belief***) to affect "present changes" ***in the past*** was indeed a good proxy of the real future - ***current present***. That is, the expected pattern of behavior simulated in the past by the anticipatory systems (the virtual future then) coincides with the actual real future, that is, the established behavior, the actual present now. Is this a violation of the causal foundations prescribed by the paradigm of reductionism? It is not a violation, but as shown by the previous three sentences, it is pretty confusing when coming to the handling the references to time;

 # 2 - any information space (repertoire of narrative, essences, observer-observation complexes, anticipatory models) used to generate an useful local observation (to gather useful data about the given associative context) and to run anticipatory models, must be tailored on the structural organization associated to the identity of the agent. For example, such a tailoring can refer to the space-time domain of operations (the monitoring done by an eagle must necessarily have a different nature from the monitoring done by a bacteria) or the characteristics of the associative context (a human looks around mainly in daylight versus a bat which "looks" around mainly in the darkness).

3.3 What remain the same when the system becomes something else?

In his seminal book "from Being to Becoming" Prigogine (1968) makes the point that self-organization in dissipative systems implies a peculiar characteristics of living systems: they must be "becoming systems". If we accept the statement that "life is unavoidably associated with evolution" we are faced with another difficult question for reductionism. What is that remains the same when a system becomes something else? This question is not addressed by hard scientists used to describe becoming systems using numbers. However, this question has been addressed in complexity theory, especially by those looking at the complexity of life. In relation to this point we can use a narrative proposed by Koestler in his famous book "The Ghost in the Machine" (1968 pag.87). According to Koestler it is impossible to individuate and define in formal terms what a given opera of Puccini – e.g. La Bohème – is in reality. In fact, we can assist to various representations of it (individual realizations), which would be all different from each other. *At the same time, the very same representation is always perceived as "La Bohème" even if in different ways by different spectators (non-equivalent observers). Such an opera was conceived as an individual "essence" by Puccini, but then it was formalized (encoded) into a set of formal identities (e.g. manuscripts with lyrics, musical scores, description of costumes and set decorations). After that, various directors, musicians, singers, costume designers willing to represent "La Bohème" have adopted different semantic interpretations of such a family of formalizations. To make things more intriguing it is exactly this process of semantic interpretation of formal identities and consequent action - what implied the generation of a new generation of formalizations- which managed to maintain alive such an individuality. The individuality of "La Bohème" will remain alive only in presence of a continuous agreement among: (1) those providing representations (producing realizations of it), that is musicians, singers, administrators of opera theaters, etc.; and (2) those making the production possible (those supporting the process of realization), that is the spectators paying for assisting to these representations and/or sponsors of the opera. That is, the surviving of the identity of "La Bohème" depends on the ability to preserve the meaning assigned to the label "La Bohème" by interacting non-equivalent observers. This keeps alive the process of resonance between semantic interpretation to previous formalizations of the relative set of identities required to generate a new generation of formalizations to be semantically interpreted*' Giampietro, 2003 (pag. 60-61)

Before getting into an analysis of the various steps of this process we have to mention very briefly the work of Tarsky on the possibility of defining a criterion for truth of formal statements. In a seminal paper of 1944 Tarsky makes the point that the truth of a statement expressed using a formal language can only be verified by looking at the correspondence of meaning between a "metalanguage" and an "objective language". The famous "line" used by Tarsky to make this point is – "snow is white" (a formal statement made using the objective language) is true if and only if snow is white (a perception obtained using the metalanguage). Therefore, the possibility of determining that such a statement is true depends on the possibility of establishing a relation of congruence between non-equivalent statements provided simultaneously by a metalanguage (in terms of external referents providing meaning to the statements) and an objective language (in terms of a symbols exactly specified in terms of syntactic rules). A visualization of the application of this metaphor to the idea of the preservation of a musical piece is given in **Fig. 4.** To make our life easier, in this example, rather than the reproduction of an opera of Puccini we are considering the reproduction in time of only a series of sounds associated with a fuga of Bach.

Fig. 4 – The various steps of the process of reproduction of the essence of a Fuga of Bach

The successful preservation of the essence of a piece of music is associated to the ability of:
#1 establishing a resonance between a realization of an instance of "written music" – e.g. a score - which is translated into an instance of "performed music";
#2 recognizing the "performed music" as a legitimate instance of the given piece of music that is associated with the goal of preservation; and
#3 closing the cycle, by translating back the realized instance of "performed music" into a realized instance of "written music" that can be used again in the future to restart the cycle.

This resonance between: (A) representation of instructions about how to carry out a physical process; and (B) the actual implementation of a process writing instructions, recall the ideas already mentioned of Herbert Simon (recipes → making processes → making recipes) and Prigogine (DNA → making metabolism → making DNA) as the basic impredicative loop determining the special nature of living systems. In relation to the crucial role that the semiotic process plays in this process (and therefore in the origin of life), we can note that this iterative resonance requires the ability to TRANSDUCE between "***individual realized instances***" (in the physical processes) of what has to be preserved and "***representations based on types***" (in the information space) which can be replicated and stored using formalizations based on an objective language (that is recorded in physical structures). In particular the step TRANDSUCE implies: (i) in one direction, the mapping of individual realized instances of an essence (the actual sound of the music of the fuga) into a set of categories identifying the formal identity of types associated with that essence (the score of the fuga); and (ii) in the other direction, the mapping of expected relations referring to the representation of functional and structural types (the availability of musicians) onto an actual fabrication of instances of the given essence (the playing of the score). In conclusion a successful resonance capable of preserving the essence of a musical piece entails:
* the ability of generating "performed music" – i.e. legitimate instances of the given essence – individual realized instances of the Fuga - on a space-time domain much larger than the one at which the individual instances of "written music" – individual realized instances of scores - are fabricated and/or played according to the formalization.
* the possibility for those listening to the performed music to recognize the piece which is played as a legitimate member of the equivalence class associated with the relative essence. This second requirement entails the existence of the role of a "recognizer" – someone or something has to "decide" about that. The decision of the "intepretant" (deciding about the meaning to be assigned to the realization) is about whether or not there is a correspondence between what it has been established according to information carried by the "objective language" (what is proposed, so to speak, as an instance of the fuga by the pianist playing the written score) and what is expected according the "metalanguage" (what is known to be the fuga by the recognizer, who is listening). Therefore the possibility of having a check on the truth of a statement – in our semiotic process the successful reproduction of a Fuga - entails the existence of a "recognizer" looking for something "to be recognized" – **Fig. 5**. Again we are forced to deal with the final cause as a key factors determining the possibility of transmitting, perceiving and representing information in general terms. As discussed before about "La Boheme", this implies that the task of preserving the given essence must result relevant for the stabilization of the input of resources needed to keep operational the semiotic process. In the example of La Boheme: (1) the spectators attending representations of the opera, private sponsors, and the public administrators regulating the opera theatre, must be willing to pay the salary to those performing genuine instances of La Boheme reproducing and interpreting formal identities of it, as well as to cover other costs; (2) enough people in a given society must decide to devote their lives to artistic activities. This is a must in order to have an adequate supply of good opera singers, musicians, directors, scenographers, costume makers, etc.

In **Fig. 5** the recognition is contextualized in relation to the "playing of" and the "listening to" a Fuga of Bach – it has to do with recognition based on expected patterns in sounds. As discussed about "La Boheme" opera, different narratives can be used for such a recognition. They can focus on the lyrics, the costumes or other relevant attributes as the typologies of interest to be considered in the objective language. That is, using different narratives would have implied the use of different ways for establishing a link between the "objective language" and "metalanguage". Please note that in the example given in Fig. 5

two languages are used for different functions. The use of the objective language is about **fabricating an individual instance**, whereas the use of the metalanguage is about **assigning meaning to an individual instance**.

Fig. 5 The steps of the semiotic process in the reproduction of the essence of the Fuga of Bach

To make things more challenging for the reader, in the example given in **Fig. 4** I imagined that the fuga of Bach can be represented using two non-equivalent "objective languages" for fabrication – different typologies of formalizations of the semiotic identity of the same essence. That is, in the bottom left part of **Fig. 4**, we have two non-equivalent ways which can be used to write the fuga – "snow is white/A" and "snow is white/B":

* *the objective language A* determined by the use of the traditional grammar associated with the writing of music in western sheet music. It is made of: (i) a ***staff*** (a given referential frame made of 5 parallel lines); (ii) a ***clef*** (indicating the reference value for the notes); (iii) ***time signature*** (indicating the quantity of bits per bar, a sort of quantization of the time when defining a "scale" for the timing of the execution); (iv) ***notes*** and ***rests*** (the data input in the grammar) - indicating both the duration and the pitch of the sound. This grammar provides: (a) a particular lexicon - the universe of possible notes to be played, which is only partially overlapping with those of Japanese or Islamic music; (b) production rules - the meaning to be assigned to signs; (c) a data set entered using such a grammar; (d) the overall structure of the process of fabrication of instances. This grammar ***makes it possible to interpret data*** (the specific data set of notes associated with the specific score of the Fuga of Bach) ***in relation to the specified goal***: generating an instance of this piece of music by a pianist.

* *the objective language B* determined by the use of a mechanical grammar associated with the music rolls used in Barrel Organs. In this case, each hole across the roll marks the pitch of each note, whereas the speed of the roll defines the tempo of the various notes. In this case, it is the given "determinateness" of the associative context in which the process of interpretation of this objective language is performed, – the roll is read by a machine! - which guarantees the correct interpretation of the data input - the location of the holes on the music roll.

Therefore, in **Fig. 4**, we can see the simultaneous existence of:

* two "***realized instances of formal representations***" of the given piece/essence "Bach fuga": (A) the score, and (B) the music roll.

* Two non-equivalent "***processes fabricating realized instances of the represented essence***" (A) a pianist playing the fuga on the piano; and (B) the Barrel Organ player using the music roll of the fuga.

* Two non-equivalent "***realized instances of the same essence***" – (A) a series of sounds mapping onto Bach fuga coming out from the piano; and (B) a series of sounds mapping onto Bach fuga coming out from the barrel organ;

These couplets of: representations, processes of fabrication, and the realized instances of the given essence are mapping onto a shared meaning about the existence of the Bach fuga. In fact, both musical performances are recognized as the Bach fuga by the person listening to the music – the recognizer. This implies that such a recognition don't refer only to the patterns of sound generated by the process of execution (local scale process), but also by an experience which is provided by previous knowledge of the fuga (large scale process), which is stored in a memory of the recognizer. When listening to the music the recognizer looks for the expected pattern in sounds that will be associated with the essence.

In the upper left corner of **Fig. 4**, in the box labelled as "TRANSDUCE/ACT" we have the step of ***decoding***. In this step, the formal representation, which is based on types, is interpreted to guide action aimed at generating a realization of an instance of what is represented. This would be the score being read by the pianist in order to execute the fuga. To close the cycle and establish the resonance "recipe → process → recipe" it is necessary to have also a step of ***encoding*** in which a given realized instance of an essence – an individual instance of the music of the fuga - is characterized using a set of formal identities and represented as a type. This is illustrated by the label: "TRANSDUCE/REPRESENT/ACT", inside the box, in the lower right corner of the figure. In this step of encoding the semiotic complex is generating the SYNTAX required as the formal input for the decoding step.

According to what said before we can define ***the act of encoding and decoding as the act of establishing a mapping between an objective language*** (symbols associated to types) ***and a metalanguage*** (semiotic identities – shared meanings - previously associated to individual realized instances of an essence). This implies that the information useful for realizing a fuga of Bach has nothing to do with the information useful for recognizing that fuga. In the same way, the information useful to recognize and represent lyrics of a song is different from that useful to recognize and represent music. It is the ability to choose the right type of information in the right context and in relation to the right task, which makes it possible to execute correctly the step TRANSDUCE. However, again, the step transduce is logically independent from the correct execution of syntax.

3.4 The feature of grammars making it possible to get a semantic closure

The semantic closure over a semiotic process can only be obtained when the meaning of a combination of formal statements is checked against their usefulness in guide action. That is, the semantic closure of a semiotic process comes when the information has been proved "useful" in a physical process capable of fulfilling the goal for which the information has been reproduced and interpreted. In turn this requires the simultaneous establishment of two (or more) physical processes reproducing and using information at two different scales. In relation to this goal it is useful to introduce the concept of grammars as tools needed for handling this task.

3.4.1 Grammar in action: how to write a rejection letter

The concept of grammar is extremely useful, since it is about handling the relation between semantic categories and formal categories. Therefore, it can be used to tackle the challenge of how to give an operational structure to a semantic representation (a perception of a given issue), which later on has to be translated into a formal representation (a quantitative representation).

Before defining the concept of grammar in formal terms, we illustrate the actual working of a grammar in a familiar situation. To this purpose, we present in Box 3.2 the texts of two rejection letters received by a student who applied for college admission. The texts of these two letters have been generated by using the Random Sentences Generator (http://www-cs-faculty.stanford.edu/~zelenski/rsg/grammars/). These two letters are instances of text belonging to a universe of possible texts that can be generated using the set of rules determined by the software written to fulfil the task of generating "a candidate rejection letter". Obviously, using the same approach used in generating the software for writing a "rejection letter" it is possible to generate other grammars that would result useful to write "suicide notes" or "reports of a travel by train".

***** BOX 3.2 Two instances belonging to an equivalence class of rejection letter *******

Letter 1

Dear Candidate, we appreciate your interest in Harvard University. This year's group of applicants were the strongest we've yet seen. This year's applicant pool included 58 class presidents, 235 virtuoso pianists, and an unprecedented 446 valedictorians. While we were impressed with your academic determination you didn't make it. If it is worth any consolation, we considered your application until at least the second to last cut before dropping it. Remember that, in the long run, where you go to college is far less important than what you learn there, not only about the subjects you study, but also about yourself and about others. Sincerely, The Office of Admissions

Letter 2

Dearest Applicant, Thank you for applying to MIT. We would like to start off by saying that this year's applicants made selection a very difficult process. Unfortunately, as you could probably tell from the thickness of the envelope this came in you were not accepted. We feel part of what makes our University so strong is its bright and ambitious student body. Not every student whose credentials meet stated minimum standards can be admitted. I am sure that the college you now choose to attend will benefit from your talent, energy, and enthusiasm. We wish you luck in your future academic endeavors. - The Office of Admission

****

An example of the *structure* of the grammar used to generate the text of this class of rejection letters is illustrated in Fig. 6. The "whole" of the letter of rejection, which is interpreted as the large-scale unit of meaning, is characterized as a sequence of *holon-sentences,* which are the local-scale units of meaning to be organized in the right sequence. I use the term holon-sentence to indicate that a lower level unit of meaning in this letter must have: (i) an organized structure (a string of words) - at the local scale, level n-2; (ii) a well-defined functional role coded to it (the string of word have to "mean" what is supposed to "mean") – on the interface local/meso scale, level n-1; and (iii) it has to be placed in the expected order when observed on the interface meso/large scale, level n. At the local scale (level n-2), the strings of words are instances of structural types (syntactic elements) defined as a word or a string of words. They may have a meaning at the meso scale. At the level n-1 strings of words are organized following syntactic rules. The functional role of the holon-sentence can only be checked looking at the overall task assigned to the whole letter – level n. The task is to communicate the rejection of an application to a candidate who applied to the University. Therefore the functional role of the holon-sentences is to play the "right role" within their own context - i.e. the letter. In Fig. 6, the functional roles performed by the various holon-sentences in a rejection letter is associated with the various local meaning assigned to them. These meanings are indicated by the eight semantic labels (represented by the vertical series of boxes on the left of the figure): (1) salutation → (2) intro → (3) bragging → (4) contrast → (5) dropping the bomb → (6) reason → (7) cushion → (8) closing. An alternative semantic definition for step (3) could be "beating around the bush".

Fig. 6 Example of the grammar used to generate an equivalence class of texts of rejection letter

For each one of the eight holon-sentences, required as key components of the integrated set of functional roles making up the message of a rejection letter, we can define, at a lower level, an equivalence class of different structural types that could be used for its realization. For example, in relation to the fifth functional role of "dropping the bomb", we list six different sentences in Fig. 6 which are all members of the same equivalence class of structural types. This equivalence class consists of strings of words organized according to the rules of English language (in the analogy with the grammars operating in life this would the physical laws to be applied to a limited set of chemical compounds – the letters - so to speak, to have a viable structural type – e.g. an amino acid). This example represents a "many to one" (degenerate) mapping of different structural types (strings of words) onto the same function "dropping the bomb", included among the expected functional units of a rejection letter.

The grammar can be made more flexible by expressing the elements of equivalence classes (the holon-sentence needed to perform a functional/semantic role) in terms of other equivalence classes (other lower level holon-sentences). This can be obtained by substituting a word belonging to one of these strings with a *label* to be interpreted as a symbol for something else. For example, in Fig. 6 the label *hotshot1* is employed in the sentences embodying the third functional role of bragging. As shown in Fig. 6, the label *hotshot1* is then associated to another equivalence class of words or phrases (syntactic elements) indicated by the same label *hotshot1*, such as “merit scholars” or “child prodigies”.
This example wants to show that a grammar is a conceptual tool that makes it possible to:

1. Handle a representation of a set of expected functional relations among holons, by indicating a structural organization based on functional types. In this way, a grammar can establish a set of semantic bridges between different requirements of functional and structural organization across levels.
2. Provide a coherent representation of the expected relations across hierarchical levels and scales across the set of categories defined in the lexicon. In the final text obtained following the rules of this grammar – i.e. in instances of letter belonging to the same equivalence class shown in in Box 3.2 - we will find different combinations of strings of letters belonging to different holon-sentences which can be defined at different hierarchical levels, but they will all map onto the same semantic meaning of the letter (when considered as a whole).

In order to obtain the semantic closure, we must satisfy at the same time two production rules referring both to semantic structuring (the combination and ordering of the entire set of functional units) and syntactic structuring (the choice and the writing of the strings of letter).

The first set of production rules applies to the expected relations among semantic elements at the large scale – the meaning of the whole**.** For example, the whole letter (unit of meaning defined at level n) and the eight meaningful parts (units of meaning defined at level n-1) have to result consistent with the set of statements “expected” by the reader and by the writer of a rejection-letter. So this set of production rules requires the proper handling of the information at the interface meso/large scale. For this task, it is important to be able to generate at the lower level individual units of meanings and then organize them correctly. These production rules are about the functional roles to be performed by individual sentences (lower-level sentences-holons) in order to fulfill the semantic structure required by the “goal” of the whole letter (the purpose: that is why we are writing the letter in the first place).

The second set of production rules defines expected relations over syntactic elements and refers to the interface local/meso level. At the local level the syntactic laws provided by English grammar about how to couple words within a sentence and how to couple letters in the words (vocabulary). These rules are required to guarantee the usefulness of the lower-level elements used in the grammar (how to write a sentence in English correctly). Of course, these laws can only be implemented after having selected the language in which the letter will be written. That is, there is another lower level of organization (levels n-3, requiring other lower level such as n-4) that makes it possible to define holons at the level n-2. Then, when dealing with the generation of unit of meaning – for example the third element “bragging” - we may have situations in which there are “strings of words” which, in order to be defined, require additional choices: a choice among the set of options in hotshot 1, hotshot 2, and hotshot 3. However, in this case semantics does not enter in play. In fact any random choice over one of the three element of the set will do it. The grammar guarantees that whatever element of that set moved into that position will result meaningful. In this example we have two sets of beliefs referring to different levels of organization and scales that are integrated in the semiotic process:

(i) at the local scale - the belief that the different strings of words (made up of strings of letters) associated with an expected meaning are actually capable of playing the expected role of unit of meaning;

(ii) at the large scale - the belief that by combining the chosen strings (supposed to generate units of meaning at the lower level) in a given order one would be able to achieve the purpose of writing a letter of rejection.

As long as we are correctly operating the two systems of codes defined within the given grammar at different scales the result of the "correct" applications of the production rules to the given lexicon of categories defined using dictionaries will generate a meaningful letter of rejection. At this point a semiotic process can be easily implemented to check whether or not the correct implementation of the grammar is capable of getting the semantic closure. Let's imagine that rather than a rejection letter we were generating with a grammar a letter inviting the students of a university to collect an important prize in money. In this case, we would have a quite straightforward criterion of truth: after sending 100 letters generated in this way to 100 students staying at the university, we can check the number of student coming to claim the prize. In the case of an important turnover of students claiming their prize (e.g. > 80%) we can say that the grammar is useful to convey the intended message. A successful semiotic process proves that the systems of purposes and beliefs encoded in the information space organized by the grammar (or by a system of grammars) managed to get semantic closure. The letter written in order to fulfill a purpose (TRANSDUCE/REPRESENT/APPLY) was read by students and managed to obtain the intended result: they read it and came to collect the prize (TRANSDUCE/REPRESENT/APPLY).

When experiencing a success in a semiotic process it becomes possible to make a few inferences about the semantic role/meaning of lower level elements within the process. That is, the semantic closure (the integration of the meaning of lower level elements and the meaning of the whole element) proved by a successful use of the grammar implies that the set of relations determining the characteristics of lower level elements does generate "meaningful" units. Getting back to the example of the grammar illustrated in Fig. 6, in the case of the element Bragging, the meaning is preserved also when the combination of the syntactic elements (i.e. hotshots) is generated by chance. That is, after assuming the validity of this grammar for the writing of rejection letter, validated by the past success in its use, we can say that no matter how we do combine the syntactic elements at the lower level, if we follow the rules, we will always generate a meaningful "structural type" capable of performing its expected functional role – a string of words with the intended meaning – at the level n-1. The purpose (the writing of the rejection letter), the beliefs (the grammar is useful), makes it possible to formalize a criterion of truth (the success in the semiotic process).

However, the validity of the grammar in relation to the large scale purpose (to be verified at the large scale) – e.g. the order of the units of meaning – implies assuming the validity of the information space at the lower levels (that the structural types used in the eight elements are units of meaning). Moreover, the validity of this grammar (validity of local purposes, local beliefs, local solutions in terms of taxonomy and vocabularies) has been verified in the past, but there is no certainty that it will remain valid in the future. For example if we try to generate the same semiotic process in a different country. A rejection letter in a different language may keep (or may not keep) the same semantic structuring – taxonomy of category of unit of meaning - but for sure it would require (at the local scale) a different selection of words and their syntactic structuring into strings of words.

A last important point to be made about this example is that in order to achieve semantic closure the sender and the receiver of the letter must share the same expectations about the semantic organization of the grammar (i.e., the list of eight functional roles/units of meaning). If not, then it is impossible to build a commensurate experience using written information. This fact has been illustrated by the example given in Fig. 4 and Fig. 5 about the possibility of preserving in time a given piece of music. The person playing the piece of music and the person listening to the piece of music must be able to share the judgment about the essence associated with the sounds. Again we have clear distinction in relation to the definition of a criterion of truth for the formal statements. The validity of the encoding done at the lower level, generated and read within the black-box, can only be proved by the fact that black-box is operating and reproducing: if the text of the letter of rejection works, then we should preserve the grammar. However, when dealing with the processes that make it possible the reproduction of the black-box interacting with its context (what gives meaning to the text of a letter of rejection when read by others) the only criterion we can use is the semiotic process. This implies a continuous attempt to patch and update the grammar whenever it fails to deliver the expected result.

3.4.2 The scientific treatment of the concept of grammar

The more familiar notion of a grammar is associated with the structural organization of the natural language (Chomsky, 1998). In this case, the grammar is the set of rules defining what constitutes the basis and how to organize the spoken language to link in effective way semantic to syntactic statements. A grammar entails the classification of words according to their function in a sentence and the classification of sentences according to their function in a larger text. Thus, the grammar of a natural language is a system of semantic classification that is based on the characterization of functions expressed at a given hierarchical level (using categories defined at that given level) and required to perform another function expressed at a higher hierarchical level (using categories defined at that higher hierarchical level).

Kauffman (1993) proposes that the concept of *random grammars* be used to explain the key feature of systems capable of generate and record useful information in a process of autopoiesis. Building on Kauffman's idea, I believe that in general the concept of a *multi-purpose grammar* can be associated with any meta-system based on a flexible network of expected relations between semantic categories (e.g. functional types) and formal categories – what would be called in the jargon of software NAMES - generated by production rules applied to lower level elements – what would be called in the jargon of software TOKENS. As a matter of fact, any software application is a grammar that has been developed for some purpose.

In general a multi-purpose grammar entails a preliminary definition of:

1. A taxonomy, i.e., the definition of the set of semantic categories and the set of formal categories used in the grammar – the definition of "types of types" that are used in the grammar);
2. The lexicon (vocabularies) for the various categories included in the taxonomy, i.e., the elements of the different sets (names and tokens);

3. The production rules to be applied to formal categories using the distinction between *tokens* and *names*. Tokens are associated with a set of inputs which must be assigned to the grammar for its operation. Then, the production rules are associated with the formal system of inference determining the values of "names" starting from the input.

In order to be operational a grammar further requires the existence of an operator guided by a purpose. The operator guided by a purpose – e.g. an autopietic system using the grammar to store the memory about is past interaction with the external world - can provide the required semantic input in terms of gathering the right inputs for operating the grammar; and the existence of the appropriate means and capability to perform the required computation.

The reader should be aware that there is a crucial difference between a model and a grammar. Even if a grammar generates a structured set of output, it remains semantically open and requires an explicit step in which the semantic input has to be fed from the outside (the halting problem of Turing . . .). A grammar can generate a useful output only after having received a valid semantic input – a previous valid definition of goals, the choice of taxonomy and vocabularies - and a pertinent syntactic input - the entry of inputs and the execution of production rules. At this point, IF the semantic inputs are right and the production rules have been correctly executed, THEN the grammar generate the expected output useful in relation to the given purpose. However, it the external conditions have changed – e.g. going back to the example of the grammar for writing rejection letter, if the system has moved in a country using a different language, e.g. to Japan – not only the dictionaries have to be changed, but also the taxonomy of units of meaning and their order of presentation.

For this reason, a multi-purpose grammar is semantically open, since the selected taxonomy can be updated whenever needed (adding or deleting elements), the vocabularies can be tailored to special cases or situation, the original definition of "tokens" and "names" can be switched depending on the purpose of the analysis, the production rules can be adjusted whenever they no longer works.

Robert Rosen, in his work on complexity and the epistemological challenges associated with modeling life and evolution, proposes a distinction between complexity and complicatedness (Rosen, 1985; 1991; 2000); a distinction that can be related to the distinction between grammar and model. According to Rosen, complexity is about dealing with an expected set of relations across semantics and syntax – it requires the ability of establishing a coherent link between semantic and formal categories. In relation to this point, this fact would suggest that complexity and life can only be handled by using grammars. On the other hand, complicatedness is about dealing with an expected set of relations within syntax – it requires the ability of establishing a reliable link over formal categories within a given syntax. Complicatedness can be related to the computational capability required to operate the syntactic rules and relative data. Rosen's distinction can be used to warn against the risk of confusing complicatedness with complexity when developing quantitative analysis of life. In this situation, trying to stretch the applicability of models by expanding the level of complicatedness of inferential systems can easily fall into the attractor of formalism non-sense.

3.5 A first overview of the semiotic process in life

We can get back now to the quote of Pattee: "*Metaphorically, life is matter with meaning. Less metaphorically, "semiotic complexes" are material structures with memory by virtue of which they construct, control and adapt to their environment. Evolution entails semantic information and open-ended evolution requires an epistemic cut between the genotype and phenotype i.e. between description and construction*". Pattee 1995a

As noted earlier, the concept of biosemiotics implies a short-cut in the semiotic process represented in Fig. 5. In fact, in a semiotic process carried out by autopoietic systems the "recognizer" is at the same time the external referent (the thing to be recognized)! Put in another way, IF the recognizer is getting an instance of the type to which it belongs (if the organism has been reproduced) THEN the syntactic information about how to produce it was true in relation to both the local scale (the production of the structural type worked out properly) and in relation to the large scale (the associative context expected by the functional type was actually there). So in biosemiotics we do not need an interpretant for confirming beliefs about the validity of information, we just need survivors! We will see in Part 2 that when dealing with metabolic holon this implies establishing a relation between direct information associated with the writing and reading of genetic information at the local scale and mutual information expressed at the large scale by the communities defining the niche of a species, depending on thermodynamic processes taking place across multiple scales. I would like to close this section by providing an overview of the semiotic process associate with life. But first I have to provide a few concepts that I use for framing the epistemological predicament faced in a semiotic process. This predicament is directly related to the unavoidable existence of two dualities needed to have the generation of knowledge. The two dualities introduced by Galileo that are at the basis of the possibility of perceiving and representing a part of the eternal world are:
(i) a distinction of "the self" versus "the other"; and
(ii) a distinction of "the observed" versus "its context".

There is a series of logical steps proposed by Fichte (Breazeale, 1992) to explain the need of introducing these two dualities. The definition of the self is an absolute necessity to make the required choices on both the normative and descriptive side. The two dualities can then be explained according to the following logical steps:
1. The identity of "the self" defines the capability of having perceptions in the first place. To have a perception one must have: (i) an instance of 'a self' perceiving the external world, and (ii) a repertoire of types used for perceiving the external world. This step implies that the relevance of any perception depends on the identity of the self;
2. The structuring of the perception over recognized types implies a distinction between 'the self' – the entity that is generating the perception – and 'the other' – the self can only perceive using a repertoire of types "the external world";
3. The representation of the interaction of the self with the external world is necessarily complex. In fact, this interaction can only be perceived and represented by using different scales and dimensions of analysis. Therefore, to get an effective perception and representation of the external world that results useful in relation to a variety of different tasks, it is necessary to generate an integrated set of non-equivalent perceptions and representations of the relation between 'the self' and 'the other'.

This analysis generates an obvious problem. When considering this complex mechanism of perceptions and representations can we see "the reality" in this process? More specifically, IF the physical act of perception of the self can only be realized by instances, IF the self can only perceive the external world according to types, THEN it can only observe and represent the "external world". What about the "internal world" of the self? How is it possible for an instance of "the self" to observe "the self"? Using which typologies?

Does the "internal world" of "the self" belong to "the reality"? If we accept that the internal world of the self belongs to the reality, then we are left with the problem of how to observe it (who is observing it, a realization or a type?) and how to communicate this observation to others. This is where the unconscious of Freud and the division of the personality in different "typologies" enters into play. This discussion becomes a little bit easier when dealing with the semiotic process of life where there is not reflectivity. In any case also in the case of life we are forced to face the impossibility of perceiving and representing "the reality". Rather we can only perceive and represent a part of the reality for which we have the possibility of recognize pattern and assign codes – labels indicating expected typologies. In relation to the unavoidable problems faced if one tries to perceive and represent "the reality" we can recall here the wisdom of Eastern philosophy. Of particular interest to our discussion is the proposed dual distinction by the *Tao Te Ching* between "*the TAO"* and "*the named"*.

The TAO is something which cannot be defined in formal terms, but to which everything (including us) belongs. This would be a good analogous to the concept of "noumena" of Kant discussed earlier. The essence of the TAO cannot be completely shared among different beings when they use representations (*names*) of it. The NAMED, on the other hand, refers to the collective knowledge of the external world obtained through the shared perception and representation of "entities" to which we can assign names. This would be the analogous to the concept of "phenomena" in the duality proposed by Kant.

When framing this concept with western narratives, we can say that no individual shared perception/representation can cover the full essence of the TAO. The two translations of the Laozi's *Tao Te Ching* below show the essence of this idea:

Even the finest teaching is not the Tao itself
Even the finest name is insufficient to define it.
Stan Rosenthal (http://www.vl-site.org/taoism/ttcstan3.html)

[conceived of as] "having no name" is the originator of heaven and earth;
[conceived of as] "having a name" is the Mother of all things.
J. Legge (http://www.edepot.com/tao8.html)

The duality between "the reality" (the TAO) and "our perceptions/representations" (the named) entails the existence of two non-equivalent definitions of relevance:

- What we cannot know in substantive terms and, therefore, cannot be named: the TAO. For life the TAO is certainly relevant, since it is the "reality", which ultimately will determine the option space and define the validity of beliefs and purposes;
- The perception and representation of "our reality": the NAMED. The perceived reality is not "the reality" but yet it is the mother of all the things we know. The relevant point to be driven home for a discussion about life is that even though "our reality" is different from "the reality" it is the NAMED that is used as the external referent for the perception of the external world.

For this reason the only way to check the quality of our perceptions/representations (the meaning we assign to names and the names that we use to represent the external world) is through a successful interaction with the TAO – this is exactly what is done in a semiotic process. The external referent giving meaning to life can only be checked through a semiotic process, that is by commuting between the NAMED (represent) and the TAO (act) using semantics (transduce) when crossing the border within the two. In this process the ultimate goal of life is therefore that of tailoring different definitions of "the external world" in a way that makes it possible the sustained interaction of informed agents reproducing themselves, even if they are using an integrated set of names (a diverse information space associated with the NAMED) to perceive, represent and model their interaction within the TAO.

In conceptual terms we can describe the semiotic process organized over the two dualities discussed earlier as represented in Fig. 7.

Fig. 7 The handling of the two dualities – "the self" vs "the other" and "the observed" vs "the context" – during the semiotic process

After having introduced these concepts we can visualize the semiotic process of life as a process that implies a continuous commuting between "the TAO" – physical interactions in the external world - and "the NAMED" - the universe of perceptions (associated with essences determined by the semiotic process) and representations (associated with recorded information) available in the available information space used by life. It is important to observe that none of these two part could "exist" (be imagined) without the other. An information space does not exist if there is nobody using the information to transmit meaningful messages. An external world could not be perceived or represented without having narratives, models and categories to define data. So the NAMED is something that it is not material and the perceptions and the representations of the external world do not refer to the reality, but to the experience accumulated about how to interact with the external reality. Identities, beliefs, purposes, essences and the "relevant reality" are all maintained in the semiotic process through the continuous commuting between the external and the internal world of information and physical processes taking place simultaneously across levels and scales.

Fig. 11 An overview of the semiotic process of life commuting between the TAO and the NAMED

(i) on the top of the figure – we can find the physical processes taking place in "**the self**", in the internal world, that is not either perceived or represents. It is in the internal world that the messages are received, transmitted and interpreted giving meaning to the information space. Without "the self" capable of processing information and giving meaning to the information space stored in the NAMED it would not be possible to have neither perceptions (about the existence of relevant essences) nor observations (about the interaction with instances of these essences). This overview fully supports the idea of Margalef that the autopoietic process of living systems makes it possible, thanks to the hierarchical organization of life based on informed autocatalytic loops, to send messages to it-self into the future (Margalef, 1968). In this way, we can solve also the problem of the maker needed to give meaning to the whole process. In fact, like in the example of the recognition of the Fuga of Bach in Fig.4 and Fig. 5, in life if the listeners can recognize the information that has been sent to them (if the semiotic process is closed with success) then there is an effective communication of information within life itself at two different points in time (before and after the updating) via the context within which life is operating. Clearly, the "time" defining a before and an after is not "simple time" but a complex time (Giampietro et al. 2006), since life operates simultaneously across different scales. In the case of the semiotic process if a living system is receiving the message it means that it is alive, and that therefore the information it is using and reproducing is meaningful. If the system is not receiving the message there is no information to talk about – it is just matter without meaning. The effect of this continuous transmission of information of life to itself is a continuous update across the hierarchical levels of organization of the identity of the different elements making up life. There are two types of identity to be reproduced: (i) the identity of the whole (the hierarchical organization of whole holarchy); and (ii) the identity of lower level holons (the lower level elements generated and tested in the semiotic processes). That is the evolution of life on this planet has implied and a continuous update of the overall organization of Gaia (distributing the flow of information among non-living self-organizing processes, living self-organizing processes, reflexive self-organizing processes associated with the "new entry" of humans) at the large scale. Lower level holons are reproduced (amplified or reduced), changed, or erased. At this point we can make a crucial distinction about the different elements generating the semiotic process of life. The larger whole – in this case Gaia on our planet – represent an instance. It is special and it has been determined by its special history. For this instance there are no beliefs, meanings or purposes. At this levels things just happen. On the contrary for the holons considered at the lower level, that have been produced in order to map onto purposes – the expected functions to be expressed by structural – there is a given identity mapping onto an essence. This essence determines the role they play within the holarchic organization. Therefore the whole holarchy, considered at the top level – usually called using various names such as God, the TAO, Gaia, "the force", the Gods, (the weaker one in semantic terms "the expanding universe after the big bang") - gives meaning to the lower level holons. The very fact that the whole holarchy exists makes it possible a meaningful definition of the identity of lower level holons. For this reason a whole holarchy hosting a semiotic process does not require justifications or purposes for its existence. It does not make sense to ask "why the whole to which I belong is there"? Because it would be like the person winning the lottery asking "why me"? If we admit that given the existence of lotteries someone has to win the lottery, this is a stupid question to ask after having resulted the winner. If no external world were available and if no consciousness were available we would not have asked such a question. If we accept as a fact that there is an external world with life, then we have to expect the existence of meanings and purposes. Moreover, these meaning and purposes are required ingredients to be expressed only at a level lower than the whole. The whole is essential, since it provides us - all of us with reflexivity and without - with a self, but the whole cannot be known or explained with names.

(ii) on the bottom of the figure – we have the set of given perceptions and representations of events leading to the semiotic process taking place in the observed world – what can be called "the other". It should noted that the semiotic process can only perceive and represent these events using the available repertoire of narratives, models, categories of data (vocabularies). Different agents gather data about the external world in different ways, using different models, expressing different behaviors, but above all operating simultaneously across different scales. This explain why there is an enormous heterogeneity in the NAMED. Coming to the dualities typical of holons, we can say that the "pragmatic step" is carried out by "instances of type" (operating on the physical process side) whereas the "syntactic step" linked to the recording and reproduction is based on information referring to "essences of types" (defined in the information space). This is the elusive category of non-material entities that it is generated in "the NAMED" within the semiotic process. The possibility of definition of this elusive category of non-material entities is due to the non-equivalent definitions of the "internal world" (in the self) "on the top" and the "external world" (in the other) "on the bottom". This distinction is essential to understand the epistemological predicament of life (and science!). The processes perceived "on the bottom" in the external world (either by living systems or by scientists) are happening in "simple time" – i.e. they are event perceived and represented not in a becoming world. In fact, their perception (observation) and representation is based on a fixed definition of types that is given and does not change, during a particular step of the semiotic process. Put in another way, at each step of the semiotic process there is a SYNCHRONIC operation of the information space. On the contrary, by definition the operations associate with the step TRANSDUCE are taking place "on the top" in the internal world implying a DIACHRONIC tension in the information space. The updating the identity of the whole and as a consequence the updating of the relative abundance and the identity of lower level holons, implies dealing with "the tragedy of change" (an expression coined by Funtowicz and Ravets to describe the problem with sustainable development of human societies) within "the self". Something has to be lost within the self – e.g. destruction of ecosystems, extinction of species, death of individual organisms, turnover of cells within organisms – in order to gain something else. This implies continuously losing meanings, purposes, functions (across different scales of agency!) associated with the set of holons defined at lower levels that are continuously replaced by new holons in the endless dance of evolution. This is certainly perceived as a tragedy (when the semiotic system which is forced to change possess reflexivity) by holons operating at lower levels, but when perceiving the process at the top of the holarchy, it is just life in action.

In conclusion we can say that "life is matter with meaning" since living entities (physical realizations of autopoietic dissipative systems) are able to generate a meaningful representation of a "relevant reality" for themselves in the NAMED, that they use to maintain and reproduce themselves. What is maintained, however, are not instances (in life instances must die!) but the essences associated with the information needed for reproducing equivalence classes of instances with a certain level of adaptability. In order to achieve this result life must be capable of establishing and maintaining across different hierarchical levels of organization and scales a correspondence between ***what is expected*** on the semiotic side (according to the descriptions given in "represent") and ***what is established*** on the physical side (according to the results obtained in "apply"). This is discussed in the next section using the metaphor of the Sudoku.

PART 2 – The handling of the semantic step (TRANSDUCE) in the semiotic process

4. Koestler "Holons and Holarchies": the ignored revolution of hierarchy theory

4.1 Hierarchy theory is a call for an epistemological revolution

The epistemological implications of the unavoidable co-existence of multiple scales to be considered when studying complex autopoietic systems was never considered seriously in mainstream science and it shows when looking at the poor performance of quantitative science applied to the analysis of life. Every time we identify a "system" to be observed, modeled and measured we are defining within our representation of such a system an abstraction about a particular portion of the external world. The chosen abstraction will reflect a given perception of that particular portion of the external world. A branch of Complexity Theory – Hierarchy Theory – deals exactly with the implications of this act of abstraction: "*Hierarchy theory is a theory of the role of the observer and the process of observation in scientific discourse. It is a theory of the nature of complex questions, that focuses on observations as the interface between perception and learning*" (Ahl and Allen, 1996, p. 27). This predicament is especially relevant when dealing with complex systems organized across multiple scales – i.e. living systems. In fact, when studying these systems we can generate simultaneously many non-equivalent abstractions of them. These potential abstractions "*are all present in the original [hierarchical] system"* but then *"which one we actually "see" is specified entirely by how we choose to interact with the system*" (italics added, Rosen, 1977, p. 229). Additional useful references on Hierarchy Theory are: Salthe (1985, 1993), Ahl and Allen, (1996), Allen and Hoekstra (1992), Grene, (1969), Pattee (1973), O'Neill et al. (1986). A good metaphor of this point is given by the possibility of observing a given person at different scales using a microscope, the naked eye or a telescope. What we see when observing (the perception that will represented) depends not only on the nature of what is observed (the body of the observed person) but also by the choice of how to observe it (the method of observation determining a descriptive domain) – Giampietro et al. 2006. This point has been made in more formal terms by Mandelbrot when introducing the concept of fractal objects. In a seminal paper he made the point that it is not possible to define the length of the coastline of Britain if we do not first define the scale of the map we will use for our calculations (Mandelbrot 1967). The same perceived entity (the coastal line of Britain) does map onto non-equivalent abstractions (or representations) determining different numerical assessments when considered at different scales. This implies that we can observe and measure an object only after having defined what type of abstraction we will use to represent it. If this is a problem

for scientists, let's imagine the implications of this for life that can be defined as "the sustained interaction of non-equivalent observers" (Rosen, 1986). The idea that a "system" - defined in general terms as a portion of the external reality - can be associated with multiple legitimate but non-equivalent perceptions and representations (abstractions) has been suggested as the very definition of hierarchical systems:
* "systems are hierarchical when they are analyzable into successive sets of subsystems" (Simon, 1962: p. 468) - in this case we can consider them as near-decomposable.
* "a system is hierarchical when alternative methods of description exist for the same system" (Whyte et al. 1969).
* "a dissipative system is hierarchical when it operates on multiple space-time scales - that is when different process rates are found in the system" – (O' Neill, 1989)

We can then define a formal identity (= the chosen representation of the abstraction associated with our perception) for each one of the specific perceptions of the "systems" in terms of a set of expected observable characteristics associated with the pre-analytical definition of a scale. This identity will reflect the particular abstraction associated with the specific perception and the choice of the scale. When dealing with a system that can be described using different formal identities it is possible to have legitimate, rigorous, but contrasting assessments. In this case, the differences across non-equivalent assessments are not due to errors in measurement or calculation, but rather to the existence of logically independent choices of the narrative (the series of abstractions used to explain causality) within which quantitative models have to be developed.

Therefore, hierarchy theory can explain the scientific predicament entailed by default by the pre-analytical step of abstraction, that is, why "all models are wrong". In fact, no matter how carefully we chose the narrative used to perceive a particular portion of the external world, it is unavoidable that other narratives referring to different aspects of that portion of the external world will be neglected. These neglected aspects always provide potentially relevant information that is not included in the chosen model. For this reason the definition of what is a "useful model" does not depend only on the quality and the pertinence of the observation process (how good are we at observing and measuring) but also on the relevance of the information given by the chosen perception (why we want to observe our system in the first place!). Here we can recall the key epistemological implication of the need of a pre-analytical definition of "the self" discussed earlier. That is, hierarchy theory introduces a key aspect to be considered for the analysis of life. ***It is the purpose of the analysis that defines whether or not the chosen anticipatory model is useful, therefore without teleology we cannot have a criterion to verify the usefulness of information used for guiding action***. For example, we can describe the behavior of a cockroach using a narrative saying that "a cockroach is a system that tends to hide to avoid the light". Then we can develop a simple anticipatory model predicting its behavior. Such a model can result useful, in spite of the radical abstraction, if we want to guess its running direction when the light is switched on in a room. Clearly, the same model will result completely useless if one wants to predict its feeding habits. Accepting the fact that an abstraction necessarily implies simplification, we have also to accept that we need a method for validating the anticipatory models to decide when the process of abstraction is useful (keeping the model simple) or harmful (making the model too simple). As discussed earlier this can only be obtained looking for a semantic closure of a semiotic process.

5.2 Exploring the implications of the concept of holon

Before getting into a formal definition of the concept of holon let's start with an example of a familiar complex system organized across different scales: the heart operating within the human body. As illustrated in **Fig.9** we can imagine the human body as the whole system (seen at the level n), including inside its circulatory system (seen at the level n-1), that includes as an internal component the heart. In turn the heart can be as a functional type (at the level n-2), that can be expressed by structural realizations of a pulsing hearts (at the level n-3). In this example we have two different structural types (a natural heart and a mechanical heart) mapping onto the same functional type (something capable to pump the required quantity of blood at the required pressure according to the circumstances). We can also imagine that the two pictures represented in the figure refers to actual instances of these two types.
Using the overview provided by this figure we can make a distinction between: (i) functional type, (ii) structural type, and (iii) individual realizations belonging to a given equivalence class of structural types (i.e. either natural heart or mechanical heart).

Fig. 9 A representation (based on abstractions) of organs within the human body

Let's define more in details these terms:
*** Functional type**
In the example of **Fig. 9** the functional type refers to the role of a pulsing heart that guarantees the circulation of blood in the human body. The definition of this functional type refers to the role played by this type (level n-2) in a given associative/structured context (the circulatory system – level n-1). The expected/expressed role must be beneficial for the larger system (the human body – at the level n) making it possible to reproduce both the functional system and the structure context. Therefore the functional type "heart" must result useful in relation to the interface "heart"/"circulatory system"/"human body". The definition of a functional type is meaningful in relation to the WHAT/WHY question, it defines what is the function of a heart and why do we need it.

* **Structural Type**
In the example of **Fig. 9** there are two examples of structural types - artificial heart vs natural heart. Both structural types are mapping onto the same functional type. They both refers to specific types of organized structures making it possible to perform the role required by the functional type. The structural type defines the characteristics of an equivalence class of instances of that organized structure. That is, a structural type is defined by a TEMPLATE (which can be formalized in a blue print) both describing and making possible the combination of parts in a way that makes it possible to express the required pattern of organization. A structural type "heart" must result useful in relation to the interface "parts"/"heart"/"circulatory systems". The definition of a structural type is meaningful in relation to the WHAT/HOW question (what is the structure of a heart and how can we make it).

* **Individual realizations of a structural type**
In **Fig. 9** we can only provide representations (e.g. images) of actual entities pumping blood for real. Any given realization of either a natural or artificial heart - an organized structure fabricated according to a given blue-print which is mapping in terms of structural organization onto the relative template – would represent an instance of this structural type. It should be noted however, that all individual realizations of structural types are special due to their specific history accumulating stochastic events. Therefore the characteristics of specific instances never coincide exactly with the expected characteristics of the type (instances of "apples" are all special!).

After introducing these examples it is possible to discuss the epistemological impasse that humans face when studying complex systems organized in nested hierarchies: when observing complex self-organizing systems humans can only perceive "holon". The basic conceptualization of "Holon" has been explored by several authors before the term was introduced.
* Herbert Simon (1962) proposes that when dealing with complex systems organized in nested hierarchy one has always to use a combination of two concepts: "organized structure" and "relational function";

* Bailey (1990) proposes the same approach, but using different terms: “incumbent” and “role”, for dealing with the organization of human societies. For example, the president of USA is a combination of the functional type – the US presidency – a structural type – a person born in America elected to the office – and an incumbent – Mister Obama, who is the particular realization of the structural type in office now;
* Salthe (1985) suggests a similar combination of descriptions based on yet another selection of terms: “individuals” (as equivalent of “realizations of organized structures” or “incumbents”) and “types” (as equivalent of “relational functions” or “roles”);
* Rosen (2000) proposes, within a more general theory of modeling relation, a more drastic distinction which gets back to the old Greek philosophical tradition. He suggests to make a distinction between: “individual realizations” (which are always “special” and which cannot be fully described by any scientific representation since any individual maps only imperfectly with the relative template, due to its unique history) and “essences” (associated with the semiotic characteristics of an equivalence class coupling a functional and a structural type). The logical similarity between the various couplets of terms is quite evident.

The common semantic message found in all these conceptualizations calls for the need of a simultaneous use of two complementing views for defining the elements (holons), which are making up ecological or social systems. The two formalizations (NAMES) for the structural and functional type are necessarily blended in the semantic interpretation of the relative coupling.

In relation to this epistemological predicament Arthur Koestler (1967; 1969; 1978) proposed the metaphor of the holon. Holon is a term that has the double nature of “whole” and “part” of components of ecological or human systems which are able to express a valid identity both in functional and structural terms (for a discussion of the concept see also Allen and Starr, 1982, pp. 8-16).

Holons must fit two typologies of constraints in terms of WHAT/WHY (large scale view for defining a relevant functional type) and WHAT/HOW (local scale view for defining a pertinent structural type). This is why Koestler selected the term holon, which is a combination of two Greek words: (1) the word HOLOS means the whole with constraints from the macroscopic view (external view); (2) the suffix ON means the part or particle (as in proton or neutron) with constraints from the microscopic view (internal view). Holons therefore can be considered as a sort of “*natural semiotic identities*” expressed by elements of ecological and human systems that humans must adopt in order to perceive and represent them. Holons entail a major epistemological problems: *the scale useful to perceive and represent “realizations of organized structures” is different from the scale useful to perceive and represent* “*functional relations*”. An example of this impasse is illustrated in Fig. 10 showing the two different scales required to describe “why/what” of a clock (on the left) and the “what/how” of a clock (on the right).

Fig. 10 The mismatch of scale when looking at the information relevant for WHAT/WHY and the WHAT/HOW in relation to a clock

4.3 Using the concept of holon to explain the difference between design and emergence (how to explain the radical openness in life)

In this section I show with simple examples the reason why when dealing with holons it is impossible to have a formal one to one mapping between “types of organized structures” and “types of functional relations”. Put in another way, holons make it possible to have radical openness in organizational patterns, determined by the fact that the universe of the possible couplings of structural and functional types is open and expanding.

Fig. 11 Examples of many-to-one and one-to-many couplings of structural and functional types (from Giampietro et al. 2006)

Fig. 12, Examples of many-to-one and one-to-many couplings of structural and functional types (from Giampietro et al. 2006)

An example of many-to-one mapping (or one-to-many) between structural and functional types is illustrated in Fig. 11 exploring the existence of different versions (structural types) of a clock and in Fig. 12 exploring the existence of different uses (functional types) of a given timepiece.
* DESIGN – in the case of the examples given in Fig.11 we have the co-existence of many different structural types (many HOWs) that map onto the same functional type (the same WHY). In this situation, after defining the performance associated with a given role, that specifies the expected characteristics of the functional type, we can learn how to increase the efficiency of the structural types;
* EMERGENCE – in the example given in Fig. 12 we have a given structural type - an 'old mechanical clock' – in the holon "timepiece" - that can play a different role in a set of different couplings generating different holons. That is it can become another structural type – e.g. an 'object worth putting in a museum' – in the case we are looking for objects to be used in an exposition. This new functional type is determined by the existence of a purpose – i.e. the shared feeling of a society for the need to preserve records and a common memory of their process of learning how to keep time.

In the set of examples of couplings given in Fig. 11 the association between a structural type "designed" for a purpose and the functional type associated with that purpose – a holon by design. In this case, the structural type is known to be a potential solution for the given function. In the case emergence, the examples of couplings given in Fig. 12 illustrate associations between structural types originally designed for a different purpose capable of fulfilling a different functional type - a holon by emergence. This analysis makes it possible to explain the key role plaid by "instances" of types in the process of emergence. In fact, emergence occurs when an instance of a structural type is used in a different associative context to fulfil a latent demand for new function expressed by the semiotic process in which meaning is created and preserved. For example, looking at the examples given in Fig. 13 we can see that a special situation can define a strong demand for a role to be fulfilled by a structural type. The urgency of this "demand" for a new structural type capable of fulfilling a role is determined by processes taking place at the large scale. That is a top down causation defines a niche - an expected set of structural characteristics to be expressed by any instance capable of doing it. In this situation "anything" that can fulfill that role can be used to generate a new holon. This is to say that the "emergence" of a new holon is never a process that can be studied looking only at events taking place at the bottom. Events taking place at the bottoms are certainly crucial in determining the generation of new structures but the emergence of a new holon occurs only when other events taking place "on the top" generate the right conditions for the stabilization of the associative context.

Fig. 13 Situations in which the context makes it likely the emergence of a new holon (from Giampietro et al. 2006)

To conclude this section we can say that when dealing with the evolution of Holarchies (a system made up of holons organized on multiple hierarchical levels and scales - Koestler, 1969, p. 102), we should expect a continuous loss of a one to one mapping between realizations of structural types and functional types. More specifically:
(i) When we can assume as valid the definition of the functional type, then we can have many structural types mapping onto the same functional type (many hows for the same why). In this situation, the different performances of these different structural types can be compared. Here we are in the realm of design and efficiency.
(ii) When a change in boundary conditions makes it possible the establishment of a new holon, a virtually infinite universe of whys can be assigned to the same how, depending on the circumstances. This is the realm of emergence. ***Emergence by definition cannot be predicted from within the scale used by models describing the behavior of systems***. In fact the meaning of the functions expressed by the system can only be perceived at a scale different from the one adopted by model describing the behavior of the system! This implies that when dealing with the analysis of the evolution of complex adaptive systems it is impossible to maintain over time a valid formalization based on the existing coupling of structural and functional types. When facing emergence, models no matter how validated and sophisticated, will become useless in addition to being wrong. This is the realm of ignorance faced by models asked to deal with

evolution and emergence. This is the standard predicament faced by life when interacting agents are driven by anticipatory models of each other behavior. These agents must rely on models that cannot provide reliable predictions. The impossibility of predict emergence implies also that the check on the validity of a new holons can only be done, as already stated, through a semiotic process verifying whether or not the new coupling is good at expressing a new useful function.

5. The "naming of the Tao" in the semiotic process: the endless dance between thermodynamic constraints and useful information across scales

5.1 The metabolic pattern of ecosystems: synchronizing processes across levels of organizations and scales

In the 80s, the field of evolutionary studies experienced a wave of new concepts and ideas associated with this different attempts to associate the revolution of non-equilibrium thermodynamics to the issue of life. All these new narratives were based on the acknowledgment that biological systems are thermodynamic systems, operating across different hierarchical levels of organizations (and scales), stabilized, far from thermodynamic equilibrium, by a process of self-organization induced by informed auto catalytic cycles (Brooks et al. 1989, Brooks and Wiley 1988, Depew and Weber 1985, Ho and Saunders 1984, Layzer 1990, Prigogine 1967, 1980, Ulanowicz 1986, Weber et al. 1988, 1989). In other words, these ideas were implicitly stating that living systems are capable of expressing semiotic processes. In spite of the many conceptual difficulties faced by these attempts – mainly generated by the controversial use of the terms "entropy" and "information" (e.g. Collier 1986; Morowitz 1986, Wicken 1987) – these new narratives did provide new ways to conceptualize and also to represent the evolving process in complex adaptive systems based on metabolic networks.

Theoretical ecology has studied the phenomenon of hierarchical organization of flows of energy and matter in natural ecosystems and more in general in dissipative networks (e.g. Margalef, 1968; E.P. Odum, 1971; H.T. Odum, 1971, 1996; Ulanowicz, 1986, 1995). The application of non-equilibrium thermodynamics to the process of self-organization of ecosystem development was worked out by Kay (2000) and Kay and Schneider (1992). In particular, a very popular visualization of this relation was proposed by the American ecologists E.P. Odum and H.T. Odum with a methodological approach capable of generating quantitative analysis associated with the notion of *ecosystem metabolism*. Their approach makes it possible to categorize typologies of ecosystems in terms of expected relations between fund and flow elements (Odum H.T. 1956, 1957, 1971; Odum E.P. 1968, 1969, 1985). An example of the results obtained with this approach is given in Fig. 14. Other theoretical ecologists have worked in the same line suggesting alternative methods and criteria for defining ecosystem types – e.g. Allen and Hoekstra 1992, Jorgensen 2009, Margalef 1968, Ulanowicz 1986, 1997.

Fig. 14 A representation of the metabolic pattern of ecosystem (described in terms of fund and flow elements) and expected characteristics described as fund/fund ratios and flow/fund ratios

The meta-narrative of the Odum brothers provides a robust theoretical framework to study metabolic patterns expressed by ecological systems in terms of a resonance between thermodynamic and semiotic control. A metabolic pattern reflects the possibility to integrate into a coherent network, that is defined by expected relations over nodes (the fund elements) a set of transformations (processes associated with the flow elements) taking place at different scales across different hierarchical levels of organization. The concept of ecosystem therefore establishes a bridge – on the biophysical side - between key biological characteristics of the various elements making up an ecosystem – e.g. cells within organs, organs within organisms, populations within functional compartments – and the characteristics of the emergent properties expressed by the ecosystem, observable only at the level of the whole ecosystems (Odum E.P. 1969, 1985, Odum et al. 1995). On the other hand the characteristics of the elements can be determined by recorded information (e.g. blue prints) about how to produce the structural types determining the structural characteristics of the holons.

To achieve this result:

* networks must be able to self-organize simultaneously across different hierarchical levels of organization and different scales: (i) connections among the different parts of the ecosystem (meso scale) - e.g. herbivores feed on plants and carnivores feed on herbivores; (ii) specific metabolic characteristics of the different parts, when described at the local scale (small scale) – e.g. the input/output ratios associated with each parts; (iii) the resulting emergent characteristics of the whole ecosystem (large scale) – e.g. the black-box interacting with its context.

* networks must be able to define different categories of "energy forms" that are non-equivalent and not reducible to each other. For example, within an energy diagram describing the metabolic pattern of an ecosystem the "energy input" used by carnivores – one of the fund element of the network – is represented by joules of herbivore biomass. But when considering another element of the network – e.g. herbivores – the "energy input" of herbivores is a different, non-equivalent, energy form 1 joule of plant biomass. For this reason Odum (1975) refers to these graphs as representation of *energy chains* (Odum 1975). This concept implies the need of a pre-analytical definition of the set of different *energy forms* that can and should be used to obtain feasibility in relation to external constraints – when considering the whole ecosystem as a black box with boundary conditions - and viability in relation to internal constraints – when considering the congruence over the characteristics and the relative size of the parts interacting within the black box - (Odum and Odum 1976, Odum H.T. 1971). We can imagine that the definition of different energy forms that are specific for different elements of the network works as a system of code used to modulate the expression of local metabolic patterns integrated in larger metabolic patterns. In conclusion we can say that the concept of metabolic pattern of ecosystem is perfectly consistent with the concepts discussed so far:

(i) self-organizing systems are dissipative structures that gets a comparative advantage by disposing as much entropy as possible (Glansdorff and Prigogine 1971, Nicolis and Prigogine 1977, Schneider and Kay 1994). "*A given dissipative system represents an observable pattern, distinct from its environment, which can be expressed and maintained as long as the gradients required for its existence remain favourable*" (Giampietro 2014). When coming to the effect of natural selection on living systems the status of dissipative (metabolic) systems implies a clear strategy for these systems *". . . in the struggle for existence, the advantage must go to those organisms whose energy capturing devices are most efficient in directing available energies into channels favourable to the preservation of the species*" (Lotka 1922, p. 147). This is the original formulation of the Maximum Power Principle (the rate of energy dissipation) of dissipative systems, proposed by H.T. Odum (Odum and Pinkerton 1955, Odum 1983, 1995), building on the work of Lotka (Lotka 1922a, 1922b, 1925), to explain the evolutional drive of ecosystems. However, to avoid to clash against boundary conditions at the large scale, it is also important to try to reduce the impact on the environment per unit of biomass (Minimum Entropy generation principle), explaining the Yin-Yang tension typical of life (more on this in the discussion of the adaptive cycles);

(ii) complex self-organizing processes based on "autopoiesis" requiring two conditions: (a) compatibility with biophysical constraints at any moment in time (external constraints – the same as for all dissipative systems); (b) the ability of retain information about past interactions with the external world, in order to be able to preserve and reproduce the identity of the system (internal constraints). In relation to this point,

H.T. Odum coined the expression of "*informed autocatalytic loops*" in order to describe the process of self-organization of ecosystems.
(iii) the concept of *negentropy* as proposed by Schrödinger (1944). This concept introduces a radical departure from the assumption of classic thermodynamics whose laws are applicable to all natural systems in any point in time independently from their specific history (Giampietro et al. 2013). The term "negentropy" indicates that the definition of what should be considered as a useful input depends on the special identity - determined by its history - of the metabolic system considered. This information if encoded in the information used to generate metabolic patterns at different scales, can be used to integrate the compatibility of processes taking place simultaneously across different scales.

In conclusion we can say that the analysis of a metabolic pattern requires defining the specific set of "energy forms" associated with the identities of the various elements of the ecosystem. Then the turnover time of individuals within the species has to be compatible with the turnover time of the biomass making up the various functional compartments (made up by a mix of different populations/species) that are expressing the functions needed for reproducing the whole ecosystems – i.e. recycling the nutrients in order to maximize the ability of available exergy inputs. To indicate this integrated effect of mutual compatibility, in which the various compartments have to represent inputs of "negative entropy" for each other Giampietro and Pimentel suggested the name of *negentropy chains* to describe this complex pattern of self-organization typical of ecosystems (Giampietro and Pimentel 1991).

A self-explanatory view of the co-existence of two non-equivalent definitions of boundary conditions determining the feasibility of elements of the ecosystems is given in Fig. 15.

Fig. 15 The formation of a network niche for a metabolic elements defined by nodes made of metabolic elements with stable identities and a stable structure of connections

There are boundary conditions defined for the "whole ecosystem" when perceived as a black-box (adopting a large scale view) and there are boundary conditions defined for fund elements operating inside the ecosystem at the local scale (the border around individual elements operating within the network). This is a very common property of complex metabolic systems – e.g. cells within a human being are operating at a constant external temperature (around 37 C) whereas human being are operating under a wide range of external temperatures. Getting back to the case of ecosystems the required congruence between matter and energy flows exchanged inside the whole (parts and the black-box) and matter and energy flows exchanged by the whole with its context implies that: IF (i) we can define the metabolic characteristics of elements of the network at the local scale – i.e. because of the use of Blue Prints in their production; and (ii) we can maintain the structure of the relations in the functional compartments of the network constant in time; THEN there is a bridge between the definition of boundary conditions of the parts (defined at the local scale) and the definition of the boundary conditions of the whole ecosystem (defined at the large scale). As a matter of the existence of this mutual information generated by the network will determine an identity for network niches at the local scale.

That is, when considering the network illustrated in **Fig. 15** the combined information stored in the identities of the elements of the other nodes (at the level **n-1**), which is guaranteed by the recorded information of the Blue Print (BP) used for the production of instances of their structural type, and by the graph of connections (at the level **n**) defines a "network niche" for an element supposed to occupy the node B. That is, whatever structural type would be used to fill that position in that network, in order to be compatible with the rest, it will have to be able to process a certain set of inputs and deliver a certain set of outputs at the speed which is expected by the rest of the network. It must fit the functional type associated with the essence of that node. Put in another way, **there is an image of that element** which is stored in the mutual information carried out by the rest of the network, which is obtained when considering simultaneously different types of information stored at different levels". This image can be considered as the "essence of the metabolic holon B". It is an essence, because if the network is surviving as such, some structural type must have been expressing that function so far.

In fact, the identity of the dissipative network shown in Fig. 15 entails a congruence between: (1) the associative context (the mutual information associated with the organization of the metabolic network of which the metabolic element is a part) determining the functional type of B; and (2) the structural element capable of generating the required set of transformations at the local scale (that must be encoded in a blue print associated with a process of fabrication at the local scale) determining the structural type of B. That is the definition of the network niche – the essence of the metabolic-holon B in Fig. 15 – plays the role of the interpretant capable of recognize a given realization of an instance of the fuga of Bach are "right" or "wrong" as shown in Fig. 4 and Fig. 5.

In conclusion, when studying the process of reproduction of complex metabolic systems stabilized by informed autocatalytic loops it is necessary to use a multi-level, multi-scale analysis. In fact, the reproduction of the identity of the whole ecosystem (an emergent property expressed at a large scale) requires also the reproduction of the identity of the various elements/components operating within it at lower hierarchical levels (lower level elements such as compartments, species, organisms) across different scales:

- At the meso scale. The definition ecological systems is obtained by the expected set of relations across structural and functional compartments – e.g. plants, herbivores, carnivores, detritus feeders – (the required parts of the ecosystems). A given typology of ecosystem defines an expected relation over the relative size of these parts.
- At the local scale. The existing metabolic identities of the lower level elements (different in different typologies of ecosystems) can be populations of the species included in a compartment (e.g. populations of herbivores) or individual organisms of populations included in a species (e.g. members of a population of antelopes) or organs of organisms or components of organs like cells. The expected characteristics of these elements are defined at the local scale in terms of (i) specific definitions of "negentropy" flows – i.e. identity of required inputs, boundary conditions and the identity of the wastes for which sink capacity is needed; (ii) the metabolic characteristics of the fund element in terms of output/input ratio and the pace of the flows (flow/fund ratios); (iii) the turnover time of the instances in the typology (the pace at which the elements is eating and eaten by other elements). This determines a ratio between the relative size of the various fund elements (fund/fund ratios); and
- At the large scale. The overall assessment of the material and energy flows that the ecosystem requires from the outside (e.g., solar energy, water and nutrients input) and that leak into the outside (e.g., thermal emission, water output and nutrients leakage) tend to refer to generic definitions of boundary conditions not requiring the "specific" local definitions of negentropy. At a very large scale the ecosystems are relying on energy forms very generic that can be described using a vocabulary taken by physics – e.g. *solar radiation* is the input that is dissipated into *thermal waste*. The bio-geochemical cycles refer to chemical elements (water, nitrogen, carbon) and no longer to special chemical compounds required for specific biochemical reactions. When coming to the description of boundary conditions of whole ecosystems at the very large scale we can use a

narrative that goes back to the generic accounting of classic thermodynamics. This is what makes it possible for the ecologists following the analysis developed by the Odum brothers to have a common value of reference – solar joules – against which it becomes possible to assess the transformities referring to the various energy forms specified in the diagram.

5.2 Co-evolution of species and ecosystems across scales: centripetality and the metaphor of the Sudoku to explain evolution

The existence of network niche can better clarify the distinction between "emergence" and "design" discussed earlier. There are situations in which the organization of the ecosystem is not very strong so the identity of the various network niche is not strictly defined. In this situation we can have that a source of variability from below (innovations of structural types at the local scale) can generate a readjustment over the network depending on how the amplification of its activities affect the overall interaction of the whole network with its associative context. In this case we have a "bottom-up" driven change that is likely, when: (i) the structure of the network has not been stabilized for a very long time. That is, the definition of structural and functional types in the nodes have not been under selective pressure for a long period of time – i.e. there is still room for re-adjusting, at the local level, the WHY and the HOW (more on this when discussing the adaptive cycle of Holling); and (ii) when the external boundary conditions for the whole ecosystems are not limiting its possible expansion. In this situation exploring new solutions is not too dangerous for the survival of the whole. That is lower level changes can be reflected in higher level changes. This is a typical situation of colonization or early succession. On the contrary, we should expect the reverse situation – a "top down" drive or better "innovation by design" when: (i) the structure of the network is very well defined in terms of mutual information, meaning that the definition of functional types (the WHY of holons at the local scale) is very clear, what innovation can do is only to look for better HOWs; (ii) the whole system is severely controlled by external constraints and in this situation changes can only be explored on the inside: leaving the overall interaction with the context stable how can we re-adjust the relations inside the black-box? In order to clarify better these concepts I propose below two conceptualizations illustrating the importance of analysing the process of evolution in life, simultaneously across different levels of organization on multiple-scales: the concept of centripetality (proposed by Robert Ulanowicz) and the possible use of the popular game of Sudoku as a metaphor to study the combined effect of direct and mutual information in evolutionary patterns.

5.2.1 The concept of centripetality (Ulanowicz): how to become something else while remaining the same . . .

Another interesting systemic property expressed by biological systems is the property of centripetality, a concept introduced by Robert Ulanowicz (1997), another leading theoretical ecologist, studying evolution, using the narrative of dissipative networks. The work of Ulanowicz is extremely important for the discussion of "what is life 2.0" since he has always been extremely clear about the need of observing things "on the top", rather than "on the bottom" in order to have a better understanding of how life works. The following quote is illuminating in relation to this point: "*We are free, for example, to consider the growth and development of ecosystems without explicitly mentioning genes or DNA embedded in them. We can even conceive of a totally self-consistent and coherent body of phenomenological observations that explicitly mentions only agencies at the focal level. To some readers, talking about ecology without mentioning genes may sound like heresy, but such an approach is hardly without precedent in other fields. There exists a school of thermodynamicists, for example, that insists upon the sufficiency of macroscopic narration, which is not intended to constitute full explanation. As a student in chemical engineering science,* *I was made to toe this party line. If, in response to any question on thermodynamics, a student should utter or write the words "atoms" or "molecule", the answer was summarily judged incorrect. Thermodynamics, according to this dogma, was a self-consistent body of phenomenological observation quite divorced from any theory of atoms*". Ulanowicz (1997) p. 56-57

The concept of centripetality is really important since it provides an example of how an autopoietic system can become something else (in terms of structural types) while remaining the same (in terms of essences), by evolving at different speeds at different scales. Let's use again a quote from Ulanowicz explaining this concept: "*Autocatalytic configurations, by definition, are **growth enhancing** . . . Far less attention is paid, however, to the **selective pressure that the overall autocatalytic form exerts upon its components**. . . . Unlike Newtonian forces, which always act in equal and opposite directions, the selection pressure associated with autocatalysis in inherently asymmetric. . . . They tend to ratchet all participants toward **ever greater levels of performance** . . . The same argument applies to every members of the loop, so that the overall effect is one of **centripetality**, to use a term coined by Sir Isaac Newton: the autocatalytic assemblage behaves as a focus upon which converge increasing amounts of exergy and material that the system draws unto itself*". (Ulanowicz, 1997 pag. 46-47).

A short description of the concept of centripetality, based on the text of his book and on the graphs presented in **Fig. 16**, follows.

Fig. 16 A series of graphs explaining the concept of Centripetality

By its very nature autocatalysis is prone to induce competition. For example, suppose that A, B, C and D are sequential elements comprising an autocatalytic loop (graph #1 illustrated in **Fig. 16**). Let's now imagine that some new element E appears by happenstance, which is more sensitive to catalysis by D (graph #2). This means that the adoption of E would provide a greater enhancement to the activity of B than does A. Then E will grow to overshadow A's role in the loop, or will displace it altogether. Obviously, this very phenomenon can be repeated for other elements of the autocatalytic loops. In the same way, C could be replaced by some other component F (as in the graph #3), D can be replaced by another component G and the component B can be replaced in the same way by H. The final configuration of the sequential elements of the autocatalytic loop could become at that point E,H,F,G, - graph #4 - which contains none of the original elements". [= this is my summary of the text of Ulanowicz, 1997 found on pag. 48].

"*It is important to notice in this case that the characteristics time (duration) of the larger autocatalytic form is longer than that of its constituents. The persistence of active forms beyond present makeup is hardly an unusual phenomenon – one sees it in the survival of corporate bodies beyond the tenure of individual executives or workers, or in plays like those of Shakespeare, the endure beyond the lifetime of individual actors*." (ibid. pag. 48).

This difference in scale of operation is typical of the organization of biological systems organized over multiple levels: in a given perception/representation organisms are lower level realizations (the incumbents in the role of the holon associated with the template of the relative species) making up an equivalence class (a population) acting as external referent of the relative essence. Organisms do have a turn-over in the role assigned to the holon defined at a higher level by the species. In the same way we can see a species as a holon having a turn-over in the definition of the relative community. The 4 views of the graph given in **Fig. 16** provide a clear example of a metabolic system ***becoming "something else"*** – a semantic statement ***valid when considering only the formal identities of the lower level components A, B, C, and D*** – e.g. the set of structural types associated with the parts and the set of semiotic controls used by these structural types to express agency. On the other hand, the metabolic system is ***remaining the same*** – a semantic statement ***valid when considering the semiotic identity associated with its role as a whole*** – e.g. the emergent property that the various elements express within the loop and their functional types. In this second case, the loop over the 4 elements is considered as the whole in the larger context. That is the same black box has an improved performance when expressed by E-F-G-H rather than by A-B-C-D, as lower level structural elements. An analogous process of becoming while retaining the original identity has been discussed earlier when describing the evolution in time of “la Boheme”.

The process of centripetality explains why a better network niche for the giraffe species can be considered as a purpose for the evolution of the giraffe-holon living assuming that the survival of the ecosystem to which that holon belongs has to be preserved and reproduced. In this framework a “better” version of the holon-herbivores – a population of herbivores with a longer neck capable of eating leaves on high branches of trees - translates in a more competitive community/ecosystem to which it belongs.
We can recall here the example of the grammar for writing the rejection letter: the letter remains the same – when referring to the semantic closure over the larger loop – also when we use different strings of letter or examples of “hotshots” to play the role of functional units (Fig. 6) - when the identity of the syntactic elements of the lower level are changed. Nobody living in Japan in 1514 would recognise the society of Japan in 2014 as “the Japanese society” (lower level individuals would lose the meaning of it), but there is no problem for Japan as a country to perceive itself as the same country when looking at its historic records.

5.2.2 The metaphor of the SUDOKU to study evolution

Very few of those playing the popular SUDOKU game realize that this game provides a powerful conceptual tool to gain insight about the functioning of life. In fact, the SUDOKU provide an easy to understand example of a “grammar” determining a combined effect of different types of constraints operating on different scales capable of generating mutual information. In this way, past events are generating a path dependent reduction of the option space determined by the accumulation of information in the grammar. What is very important in the conceptual tool provided by the SUDOKU is the clear illustration that it is possible to generate coherence in the definition of pattern without being deterministic. As a matter of fact, this last statement does not apply to the SUDOKUs with which the people play! In fact, in these SUDOKU the information accumulated in the grid (as pre-written numbers) summed to the mutual information determined by the integrated set of constraints given by the rules of the game define the final pattern of numbers in the grid in a deterministic way. Therefore, in order to be able to illustrate the special features of the SUDOKU game we have to illustrate more in detail its internal system of constraints.

First of all, let’s frame the Sudoku within a more general category of games in which a given pattern – which is known ahead by the designer of the game - has to be discovered by the persons playing the game (e.g. cross-words puzzles). The players can discover the hidden pattern by following a defined set of rules - a specified grammar. The systemic structure of constraints given by the grammar must be coupled to a local input of information - a data set - provided as an initial input by the designer of the game, which is determining the individual instance of the game (the Sudoku is a typology of game, each printed version with a set of numbers written in it is an instance of it). We can recall here the example of the use of the writing and reading music based on an agreed-upon grammar to which the addition of a given input – the notes written over the staff - makes it possible to the player reading the musical score to individuate a particular tune.

The Sudoku and the crosswords puzzle are both examples represent deterministic systems. With this expression we mean that given the grammar (the set of rules regulating how to play either crosswords or sudoku) and given the initial data set (local scale specific inputs referring to the special instance of crosswords or sudoku) it is possible to find-out the given solution by executing some computations and some actions. This specific input is the set of definitions for the words “across” and “down” for the crosswords, and the initial set of “given numbers” for the sudoku. A common feature of these two games is the mechanism generating coherence in the pattern, which is based on the redundancy over non-equivalent constraints. For example, in the case of the crosswords puzzle the word “HOPE” – supposed to be written in the 33 horizontal – can be identified either because of: (i) the definition of that particular word (the local scale data set); or (ii) because of the mutual information obtained from the other words. This mutual information, however, becomes available only after having identified some of, or all the 4 vertical words crossing with the word HOPE. Mutual information becomes available in the form of constraints (accumulation of records) given by history. This represents a clear example of interlocking between: (i) direct information – the definition of the word - which is local and refers to the letters that have to be inserted inside the field assigned to the given word; and (ii) mutual information – which is associated with patterns expressed at a larger scale, and refers to the mutual information (accumulated history) determined by the expected relation over crossing words and given by other words written following different definitions.

Looking at the two examples of Sudoku illustrated in **Fig. 17**, it is important to focus on the label we have chosen for it. In the figure there are two different examples of Sudoku with the label "super-critical Sudoku" and "unviable Sudoku". The label on the left wants to recall the concepts introduced by Kaufmann (1993) of supercritical and subcritical complexity. Very briefly in a situation of supercritical complexity there is enough capacity in the system to provide a set of non-equivalent constraints/attractors determining coherent patterns, but, at the same time, the system has still enough degree of freedoms to have multiple attractors and therefore has the capacity to evolve into an option space of different final structural/functional types of organization. On the contrary a subcritical system has passed the critical threshold of information which is determining completely its final attractor (or set of attractors). A subcritical system, when going through its determined trajectory of development, is bound to be frozen into a given final configuration of structural and functional types. Because of this, it can no longer evolve into something else. By adopting these two concepts we can say that when talking of Sudokus (the games found in popular magazine) we are dealing only with Sudokus all in a subcritical state: because of the amount of history recorded in it (the set of "given numbers in the grid") they are fully determined and admit only a solution.

As a matter of fact, the class of sudokus used for newspaper games must match two conditions, they must be:

#1 subcritical, meaning that the combination of the given grammar (shared by all the sudoku) and the initial data set (the given set of numbers scattered in the grid specific for each sudoku) will determine a unique solution;

#2 viable, meaning that applying the given grammar to the given dataset (the set of "given numbers") it must have at least one solution.

On the contrary, the example of supercritical Sudoku in **Fig. 17** admits more than one solution. In fact, it admits 4 different solutions (personal communication of Prof. Nakayama). Starting from a supercritical situation, the more we accumulate history – by adding a new "legitimate" number to the grid - into the system, the more we move such a system toward a sub-critical situation. Please note, that in order to define what "legitimate number" mean in this context we need: (i) the grammar - lexicon, production rules; (ii) a realization with a preliminary input of data inserted in the grid; and (iii) an agent with enough computational capability capable of playing the game relation to a given goal (having fun). From within the representation of the game (the NAMED) when playing a sudoku, a legitimate number is one belonging to the defined trajectory (expected pattern) – if the sudoku is subcritical – or one of the possible trajectories (possible pattern) – if the Sudoku is supercritical. The "legitimacy" of a number is determined by the grammar and the past inputs of information into the grid. In the example on the left of **Fig. 17**, when performing the two steps indicated in the graph [A) and B)] we can transform this sudoku from a supercritical status to the subcritical status. The expected situation for any Sudoku game found in a newspaper, which must admit only one solution. The example on the right of **Fig. 17** is another crucial case to be considered. The sudoku presented on the right does not have a solution. Given the grammar and the set of given numbers in the grid, it is not possible to obtain a pattern congruent with the grammar. That is, the numbers entered in this sudoku are "illegitimate" according to the grammar (rules of the game).

According to the narrative and the meaning associated with the game, they should not be considered as permanent records, and actually they should be erased by the players when found to be in violation of the rules (this is why you play the Sudoku with a pencil and an eraser). This fact recalls the metaphor of natural selection which is erasing the beliefs, built around the expression of a genome, when this is not compatible with external constraints or internal constraints in the process of ontogenesis. In our metaphorical interpretation of the conceptual tool "sudoku" numbers that do not fit: (i) the given history; and (ii) the given set of rules represent just temporary attempts to be aborted and removed from the game. Therefore, numbers written in a sudoku should not be considered as records of a "legitimate history" until we do not know that they are compatible across the different types of constraints defined at different scales. As observed by Koestler life requires the ability to express a memory for forgetting. It is important to learn how to stay out of trajectories leading to unfeasible states. The Sudoku on the right of Fig. 17 entails a "mission impossible", no matter how persistent is the player that will try to work it out. The only way out in this situation is very well known in evolutionary biology "reculer for mieux sauter" (to draw back in order to make a better jump). A strategy that it is well known to Sudoku players.

The Sudoku is extremely useful to explain the difference between feasibility (physical laws) and viability (internal semiotic controls). The constraints determined by the grid format of the Sudoku and the rules of the game together define the feasibility domain for the pattern of numbers that can be entered in the columns, rows, and sub-grids. Note that this definition of feasibility does *not* depend on the clues given. As soon as numbers are entered into the grid, a new set of constraints is generated by the accumulation of history. Indeed, this input of information adds additional constraints of a new type to the original set and reduces the feasibility space into a smaller viability space. Clearly, accumulation of internal constraints may lead to lack of a solution if numbers are placed in an invalid position generating a subcritical unviable Sudoku.

By expanding our perception of the class of sudoku including also the two categories given in **Fig. 17** we can introduce a distinction between sudoku "by design" (the subcritical found on magazine) and "self-organizing" Sudoku (a supercritical still making possible emergence). If we use this distinction we can say that so far, the players of sudokus have been exposed and dealt only with sudoku "by design".

What we mean with this expression is when we play the game of Sudoku we deal with special realizations of sudoku in which the final result is already known by a designer. This is a must in order to guarantee to the player that the sudoku is a viable one and admit only a solution. But what would happen if we could study the strategy of a sudoku which is "self-organizing"? This would be the situation in which the players are actually looking for a viable final pattern starting from scratch. If this is the case, the "given numbers" entered at the beginning in the grid are not validated history, but just a set of tentative beliefs about how to achieve compatibility in relation to the different constraints making up the grammar.

At this point, we can observer that all those that play the game, perhaps without acknowledging it, are unconditional believers that the set of given numbers they see in the grid do belong to a viable sudoku. This is exactly the same situation in which a ribosome reading RNA strings execute the rules fabricating proteins, or the same situation in which an embryo develops according to the instructions written in its genome, or a flock of birds migrate. There are actions which are generated by executing production rules which are provided by a given grammar, using a given local input. At the local level biological agents execute these rules assuming that they are "true" by default. However, how discussed at length so far, this definition of a "how/what" reflecting the existence of a belief, must be validated, at a higher level, in terms of usefulness, meaningfulness, purposefulness of that action (this is illustrated in the overall scheme given in Fig. 8). The beliefs associated with a validated history have then to be validated by successful action across different scales, within the iterative semiotic process.

The examples given in **Fig. 17** can be useful to discuss the different nature of "upward causation" and "downward causation". In a supercritical situation the writing of a particular element in a particular spot – e.g. the execution of the step A) in the graph on the right: inserting the number 5 on the lower line on the left of the grid - represents an increase in the level of constraints operating on the system. Therefore, the accumulation in the system of this type of events (expanding influence of the legitimate recorded history) has the effect of reducing the degree of freedom in relation to the choice of viable final configurations. So we can say that in a supercritical sudoku there is the option for upward causation: at the local scale, the action generating new structural types – those determining the identity of a given number in a given cell – affect the possible identity of the large scale pattern – affect the definition of network niches in the rest of the grid. However, after the system become subcritical, the effect of upward causation is no longer in play. That is, after having entered the number 3 with the step B) the remaining spots are all fully determined by the constraints operating on the remaining set of empty cells. At that point it is only top-down causation that matters.

According to this narrative, when dealing with an “unviable” sudoku, it is impossible to obtain a Yin-Yang tension between “downward” and “upward” causation. It is impossible to achieve a healthy tension across levels (balancing “bottom-up” and “top-down” drivers). A non-viable sudoku can be seen as a walking dead – a couple of tigers left in the Sahara desert or the last organism belonging to a given species, which cannot reproduce. A non-viable sudoku is generated by the accumulation of “illegitimate” beliefs among those endorsed and reproduced by the biological system. In its history this Sudoku made too many bad choices when deciding how to record relevant realizations of types in its own identity. This may have been determined by a “hegemonization” of a typology of constraints affecting the strategy of development suffered in its past. That is, the player was giving too much priority to a given type of constraints (either local – looking at the 9 numbers within a box - or large scale constraint – looking at the 9 numbers in relation to columns) rather than to an integrated view of the whole set of constraints. This made the recorded history no longer compatible with the viability of future evolution. In this way, the particular instance of sudoku lost the capability of establishing a useful coupling between the effect of “downward” and “upward” causation, individuating viable holons. In an unviable sudoku it is no longer possible to find a harmonious arrangement across levels in relation to the given set of non-equivalent constraints.

The abstract definition of formal constraints to patterns of numbers in the sudoku game can be used as a metaphor to the discussion on the internal organization of ecological systems we had in the previous section. We can imagine examples of large scale constraints as those biophysical constraints affecting the closure of cycle of nutrients, water or the viability of solar radiation at large scale (affecting the whole ecosystem). Meso scale constraints can be imagined as functional relations established between macro-compartments of the ecosystems. Finally, local constraints can be associated to the behavioral patterns affecting the viability of interactions among instances of organisms and populations expressed within biological communities, or the viability of ontogenetic processes (the fabrication of individual instances).

The Sudoku metaphor illustrates also the mechanism generating mutual information when different constraints referring to different levels of organization are operating simultaneously. That is, in a subcritical Sudoku the integrated system of constraints associated with the SUDOKU grammar PLUS the given input of history recorded in the grid (the numbers already written in it) determines a set of virtual numbers, which are already assigned to the different cells of the grid, because of the relative mutual information. These virtual numbers are there also when they are not written or known by the player. In relation to this point, we can recall here the example of the virtual niche defined for the human heart - in **Fig. 9 -** or for an element of a metabolic network - in **Fig. 15**. These virtual numbers will be “***discovered***” by the players through a diligent execution of computations and relative action, when filling the graph with numbers (realized instances of these virtual numbers). This discovery of the virtual pattern already existent because direct (local bottom-up information) and mutual (large scale top-down information) has to do with the initial definition of the universe of essences belonging to the sudoku which is determined by the given grammar (the lay out of the grid and the rules of the game), and the given input of history, which has to be interpreted – using an objective language - within the institutional settings in which computation and action of the player take place.

5.2.3 The necessity of an open-ended evolution to preserve adaptability of SUDOKUs

In this section we no longer deal with a sudoku “by design” (viable and subcritical) – the Sudoku that has been prepared by a “designer” found in a magazine. What are the implications of supercriticality for an autpoietic SUDOKU? In a sudoku “by design” a legitimate valid history has been verified by the “maker” before the actual game is played. Then just a fraction of this validated history is proposed to the players – in the form of “the set of initial numbers”. This input is required in order to make the players able to re-discover the hidden rest of the given history. On the contrary, in a “self-organizing” semiotic sudoku a legitimate history to be recorded and preserved in the SUDOKU is something to be learned and earned step by step. The future of this Sudoku is still open and must remain open in order to maintain adaptability! The only possible way to go for a “self-organizing” semiotic sudoku is to execute a series of steps in which one has to be careful in making choices which are not violating any of the non-equivalent constraints making possible the survival either at the local or the large scale. However, during the process of self-organization nobody can forecast the right choice to be done. For this reason it is wise to keep a balance between the concerns for local and large scale constraints.

If we imagine now to get into the process of making a sudoku from scratch, we can find the two extreme situations illustrated in **Fig. 18**. When the grid of cells is totally empty we are in a situation of total supercriticality. Everything is possible within the huge option space of possible solution, (6,670,903,752,021,072,936,960 according to an estimation found on Wikipedia) as long as it is possible to deal with local constraints – i.e. how to write a first number in a cell. This situation, illustrated in the right side of **Fig. 18**, can be imagined as the classical situation of early colonization. The "survival of the first" (Hopf and Hopf, 1985) is the expression that best describes this situation. That is, "upward causation" (bottom-up drive) is very important when the Sudoku is wildly supercritical. The capability of establishing an actual realization of a given type in a cell – the permanent writing of a number with undeletable ink! - will affect the option space of all the other cells of the grid. So if we imagine that this sudoku is made of metabolic elements, the establishment of the first pioneers in the metabolic network will determine the nature of what will be considered as stable flows of matter and energy in the representation of metabolic flows in the networks (in relation to the identity of the nodes). When amplified over a class of individuals all belonging to the same type, the colonization of a position in the grid will affect the definition of biophysical constraints not only at the local scale, but also on the large scale – e.g. when coming to the closure of nutrient cycles. Those arriving after this first phase of first colonization of the sudoku will have to either: (i) adjust to the conditions established by the first pioneers; or (ii) take over, by eliminating and replacing the first pioneers (erasing the previous written numbers). However, when a certain level of redundancy and mutual information is established over the grid, it becomes more and more difficult to insert realizations of different types. In fact, the established pattern (reflecting the cooperation among types and individuals over the grid) represents the expression of an emergent behavior across rows and columns and the other 9x9 grids. That is, in a self-organizing semiotic sudoku "history really matters" since it is affecting the lexicon (the types found in there) and the possible production rules required to express an emergent property of the whole. New entries have to learn how to deal with what is already going on in the system at the local and at the large scale. With the progressive filling of the cells downward causation becomes stronger and stronger. At a certain point, after reaching the subcritical threshold, upward causation ceases to be a force affecting the trajectory of evolution. When this occurs the system becomes fully determined. This is illustrated in the left Sudoku shown in **Fig. 18**, where we are in a "shape in or shape out" situation. However, a total disappearance of upward causation (bottom up driven innovation) translates into the total loss of adaptability for such a system. A fully deterministic system can no longer react if the definition of external constraints is changed from outside the grid. In the example of the sudoku we can imagine a change in the definition of constraints determined either by changes in large scale boundary conditions, or by lower level perturbations. In the case of the sudoku a change in boundary conditions could be generated by a reduction or an expansion in the size of the latin square. For example, the sudoku can grow from the original 3x3 grid into a 4x4 grids implying 16 squares and a set of 16 different numbers to be arranged over large scale rows and columns – the set of essences being enlarged to 16. At the moment Wikipedia reports the existence of a specimen of "sudoku the giant" with 25 squares 5x5! Another type of perturbation can be the point of the pencil breaking down. In fact, it should be noticed that the possibility of working on a sudoku for long period of time depends on the availability of a pencil sharpener and an eraser (the process in the pragmatic step generating instance of numbers to be written in the grid!). This is a factor that very few theoreticians of sudoku would include in their analysis (look also on the top!).

This analysis points at a key point for the study of life: ***self-organizing semiotic SUDOKUs willing to retain their ability to adapt cannot know in advance their final solution because they should never arrive to a point in which they becomes sub-critical (otherwise they would not be able to evolve any further). This implies that self-organizing semiotic SUDOKUs cannot know whether or not their formal identity is legitimate, that is if their beliefs are true***. If a self-organizing semiotic Sudoku would like to verify the ultimate truth of the set of beliefs expressed when recording its legitimate history – the validity of the set of numbers written in the grid – it would have to get into a subcritical situation (a full realization of its structure). It is only in this way, that it becomes possible to check whether or not the beliefs about the grammars and the cells filled with recorded history were ultimately true. However, in this way, ***the self-organizing semiotic sudoku can only discover whether or not just one of its possible recorded histories was right in relation to the given representation of the perceived situation of boundary conditions*** recorded in the NAMED part (see Fig. 8). ***By doing so, the self-organizing Sudoku would become a dead object (so to speak)***. That is, the checking the ultimate truth of beliefs for a self-organizing semiotic Sudoku is equivalent to a suicide. In fact, after (because of) this discovery the sudoku can no longer evolve in something else, because the information accumulated in its system of control to verify the truth of the beliefs, will prevent the system to change adapting its beliefs to a different situation. Going back to Aristotle, when all the potentiality of the self-organizing Sudoku is transformed into an actual realization, the system crystallizes into something fully expressed and because of this it loses its ability to become something else. That is, a self-organizing semiotic sudoku willing to retain its capability of adapting cannot leave its supercritical status. It must be able and willing to live with uncertainty. It cannot afford to get into an excessive search for the "ultimate truth" about its future and into the legitimacy of the formalized history, since this would lead it, to an excessive specification of its semantic in terms of syntax. This overload of controls (what is called senescence in infodynamics by Salthe, 2003) would lead first to "ancient regime syndrome" and then to a permanent loss of the ability of adapt – an irreversible state of subcriticality. A very good example of the trouble generated by an excess of formalization is represented by the automatic voice programs used to handle incoming phone calls by commercial organizations to be sure to handle correctly the questions received. The voice system – based on a full formalization of the option space - asks the caller to punch different numbers in relation to different potential questions. However, as soon as the caller pose a question not included in the option space covered by the formalization, the automatic voice system is unable to handle the special situation proposed by the caller. In this example, no matter how sophisticated is the software, it will fail miserably, even if the caller is asking a trivial question, when this question is not included in the list of the given software.

On the other hand, in order to minimize the possibility of introducing fatal errors and to reduce to a minimum the effect of the realization of wrong types in the wrong place (endorsing the record of invalid beliefs), it is wise to develop protocols and procedures helping the generation of a coherent set of realizations of types in relation to the various constraints. Formalization, compression and anticipation do help a lot, when handling records and operating systems of control. This internal tension between efficiency and adaptability move us back to the concept suggested by Kauffman (and by many others before him) of the necessity of operating "on the edge of chaos" between supercriticality (to retain the possibility of adapt) and subcriticality (to express enough coherence in the expressed patterns making possible the development of useful grammars to implement beliefs). These two concepts refer to the two distinct definitions of "change": (i) expected deterministic trajectories within a subcritical Sudoku (this is what we defined as "predictable behaviors" in a specified state space); and (ii) an open ended process of becoming based on the ability to introduce new set of congruent relations in the supercritical Sudoku (associated with the concept of radical openness). This process of becoming is not predictable because it is based on a systemic altering of the rules of the grammar (production rules – e.g. mutation in DNA) entailing the use of new numbers or symbols (lexicon – e.g. speciation or centripetality), which cannot be known at this moment. Therefore, the emergence of new essences (relevant aspects to be formalized using names/formal identities) in this process of becoming cannot be either formalized or predicted by using algorithms. An accumulation of history/constraints in a complex autopoietic system tends to reduce its capability of adaptation. This is why evolution requires the periodical reset of the system over a cycle of destructive creation, this concept has been expressed by Schumpeter (1942) in economics, by Eldredge and Gould (1972) in evolutionary biology, by Tainter (1990) in anthropology. Salthe describes the process of ageing in complex autopoietic systems in the same way by using the concept of "infodynamics" (2003). In relation to this point, in the next section I will briefly discuss the analysis of the process of evolution in relation of the metaphor of the adaptive cycle proposed by Holling.

The link that can be established between essences and realizations can be also related to the ability of establishing a link between metalanguage and objective language in the process of self-organization using the conceptualization given by Tarsky. To discuss this link let's have a look at what presented in **Fig. 19**. In the sudoku-type grid in the middle the elements in the grids belong to instances taken from 9 distinguishable typologies of elements (disks of different colors), which have been entered into the grid according to the grammar of the sudoku. At this point, the given history (the position of the given disks within the grid) plus the grammar of the sudoku determine a set of constraints on the possible positioning of disks belonging to the remaining members of the set of nine different types of disks over the grid. On the two sides of the sudoku graph we have 4 different sets of numbers (from one to nine) written using different objective languages: (i) the conventional Arab numbers used in Western languages (top, left); (ii) roman numbers (bottom, left); (iii) the Arab numbers used in Arab countries (top, right); (iv) Chinese numbers adopted also by the Japanese language (bottom, right). Obviously, we can use any of these 4 objective languages to represent a specific member of the set of 9 distinguishable elements to which the grammar of the sudoku refers to. So we will have a possible set of 36 symbols for representing 4 different versions of the same typology of sudoku. Again this fact indicates the existence of a set of "essences" generated by the conceptual definition of the sudoku game. These essences are generated by the expected relations over distinguishable elements to be inserted over the given grid using the given set of rules. The organization of these elements has to comply with the rules of the game, and this generates a progressive series of constraints affecting the option space of the process of realization of the sudoku. That is, what defines the SUDOKU essence is the co-existence of:

#1 a grammar defined as: (i) a lexicon of types (the set of distinguishable elements that will be included in the universe of discourse, and the set of elements defining the grid); (ii) the vocabularies used to define the elements of the sets included in the taxonomy; (iii) the production rules (determining the set of non-equivalent constraints generating coherence in the pattern);

#2 an institution defined as the ability to operate a set of semiotic control to express a guided action by assigning meaning to an objective language. In this case, this means: (i) a player willing to play; (ii) a maker willing to provide an instance of sudoku puzzle to be solved; (iii) an associative context making possible to express the matching between the demand of the player and the supply of the maker; and (iv) the use of an objective language shared by the maker and the player that makes it possible to verify the validity of the metalanguage.

Only at this point it is possible to establish the semiotic process generating the set of essences associated with the game of sudoku.

In fact, it should be noted that a formal system defined just in terms of expected relations over types – like the one illustrated in **Fig. 19** - is meaningless without someone interpreting and using it. The grammar and the symbols makes it possible a potential use of computational capability to guide a process of accumulation of records in a structured information space in relation to a given goal. However, in order to become an established game, we need to have the physical production of an equivalence class of physical instances (Sudoku schemes published on newspapers or specialized magazines and filled by players). In turn, this production requires (all activities taking place "on the top" outside the classic analytical framework) someone willing to execute the required computations and capable of the fabrication of instances and records (playing the Sudoku). Only under these circumstances it becomes possible that "the makers" of sudokus (selling copies of them on magazines) and "the users" of sudokus (buying the magazines with sudokus and filling the grids) keep alive the semiotic process. That is, in order to enter into the physical universe of realizations of types, the conceptual tool illustrated in **Fig. 19** needs a player willing to solve the puzzle, a maker willing to work on its preparation, and an associative context which makes it possible for them to carry out their tasks. This means that the establishment of the game of sudoku has not only to do with factors studied in "the external world" - the formal viability of the puzzle (on the information side) and the physical feasibility of the various operations (on the process side) – i.e. the capability of generating viable sudoku puzzles, printing them and the use of pencils and eraser when playing, but also with other elements difficult to specify in formal terms since they are expressed in the "internal world": the capability and willingness to solve sudokus, trust and stable relations in the context guaranteeing a fruitful relations between makers and users. Making and playing sudokus must be a meaningful socio-economic activity, this condition has to do with the existence of institutional settings playing the role of an admissible environment. Again, there is a part of the semiotic process taking place "on the top" and in the "internal world" that generally is ignored by those studying event only "on the bottom" and in the "external world". This part of the semiotic process is represented on the top part of Fig. 8 and labeled as "the self". ***The self is operating in the external world and gives meaning to the whole***

semiotic process BUT is never included among the entities that are either observed or represented in the NAMED.

When looking at the representation of lower level elements found in the NAMED, we can see the various lower level elements of a metabolic network as agents used by "the self" to track in the external world (the other) resources and to avoid threats (at the local scale). Therefore, their DNA should be considered as their representation of themselves interacting with the rest of the network. So if they can reproduce themselves by interacting in a stable ecosystem, they can be considered as relevant elements of the network carriers of reliable beliefs and useful purposes. Therefore, when imagining a metabolic network organized by non-equivalent constraints operating across different levels - like a sudoku – any individual metabolic element that is surviving will define for itself the meaning of the information contained in its semiotic controls and will represent a useful purpose for the whole. In this way, each one of the identities of the various elements will contribute to the definition of the overall identity of the whole semiotic process.

This is where the "survival of the first" effect can be explained. With their realization within a given position in the Sudoku, because of their metabolism and action, pioneer elements will determine the boundary conditions of the other elements belonging to the same grid (at the local scale) and to the same row and column (at the large scale following the food chain). So if we imagine a self-organizing metabolic network using a Sudoku-like system of constraints, such a system will have to be capable of renegotiating the definition of large scale constraints (downward causation) and the local scale constraints associated with the identity of the members of the various cells (upward causation) as long as it is building it-self. What is peculiar of this self-organizing metabolic network sudoku-like is that the various essences associated with it are not determined by mathematical rules (those which can be associated with its formal grammar), but rather by the viability of biophysical processes which reflect the characteristics of the various system of controls associated with its various elements and expressing patterns at different scales (institutional settings). That is, looking at **Fig. 19** we can say that: (i) it is possible to express rules of the relative position of the stones, latin numbers or Chinese numbers. In order to have a working ecosystem you can have different species as long as they generate an ecosystem feasible and viable simultaneously at different scales.

Before ending this section we can have a reflection on the duality between instances (all special) and types (associated with equivalence classes). If a "self-organizing sudoku" is generated by the co-evolution of living systems, then both its grammar/institutions and relative essences will reflect the learning process done in the past about an integrated set of biophysical constraints associated with the possible realizations of viable realizations of metabolic networks. If this is the case, then the result of each self-organizing sudoku will be special not only in terms of the final pattern of numbers that it expresses, but also in term of the type of grammars, institutions and essences that were used to implement it (what is included in the elements of the grid "so to speak"). In fact, each living complex is special since it has been determined by its unique history. On the other hand, in spite of this specificity, we can still study such a living complex, in terms of a meta-typologies of relations between grammars, institutions and essences (the essences to which the various semiotic controls refer to in terms of functional and structural types). This is the magic of life, which is capable of operating establishing individualities (special/unique instances) and at the same time strong equivalence class (based on structural and functional types organized over taxonomies of tasks to be performed at different scales). In an empty Sudoku an instance that manages to become a type becomes the new sheriff in town (thermodynamic gradients driving the generation of information – we are in the reign of emergence). In a crowded Sudoku the types become so strong that new instances have to either "shape in or shape out" (accumulated information filtering emergence – we are in the reign of design).

5.3 A different formulation of the adaptive cycle of Buzz Holling

Crawford Stanley (Buzz) Holling is one of the pioneers of the research about the meaning of life carried out by looking "on the top". One of his major achievements in this field is without any doubt the concept of adaptive cycle shown in **Fig. 20**. With this contribution he has provided the scientific community a conceptual tool capable of addressing, in semantic terms (!!!) the meaning of the different phases that we can expect when observing the evolution of living forms throughout cycles. Probably this is the reason he was not awarded a Nobel Prize.

Fig. 20 The original formulation of the adaptive cycle as proposed by Holling

The cycle suggested by Holling can be used to explain the meaning of successions in ecosystems development. The cycle is established over 4 phases: (1) it starts with a phase called RENEWAL (**a**) that implies the establishment of a metabolic pattern that is feasible according to internal and external conditions; (2) then we have a phase of EXPLOITATION (**r**, referring to the label "r-selection" used in the equation of growth in population ecology), in which the system grows as much as possible tracking available resources and accumulating "ecological capital"; (3) that we have a phase of CONSERVATION (**K**, referring to the label K-selection used in the equation of growth in population ecology); (4) finally we have a phase of RELEASE (**W**) in which the accumulated resources are released in order to make possible a different internal organization to better fit the given boundary conditions. This phase is required to move back to the first step RENEWAL.

In **Fig. 21** I propose to use the same division in four elements in the 2x2 matrix a matrix but I have changed the disposition of the cells and of interpretation of the labels to define the various elements. The representation given in Fig. 21 no longer refers to a cycle but simply to a set of non-equivalent perceptions/representation of life in action.

Fig. 21 The non-equivalent interpretation of the four elements of the adaptive cycle using the concept of the holon/holarchy

In the re-arrangement of the four elements of the adaptive cycle illustrated in Fig. 21 we have first of all a change in the meaning assigned to the rows and columns:

* the upper row refers to elements considered as "instances" of type (they are defined in the process side of the commuting). Therefore they are imagined to belong to the TAO, meaning that their survival, extinction or quick reproduction depends on thermodynamic constraints verified in the pragmatic step of the semiotic process;

* the lower row refers to elements considered as "types" (they are defines in the information space used in the commuting). Therefore they are imagined to belong to the NAMED, meaning that their existence is associated with the preservation of the relative essence (the meaning of the holons) that must be preserved in the semiotic process.

* the left column refers to events described at the local scale. Depending on the relation holon/holarchy considered, this may be individual organisms, when dealing with species or individual populations when dealing with ecosystems;

* the right column refers to events described at the large scale. Again the nature of the types to be used here depends on the relation holon/holarchy considered.

This re-organization of the lay-out of the cells of the matrix, does not change the labels and meaning of the four steps in the cycle, but it makes it possible to establish a relation between the conceptualization of life based on holons and holarchies and the metaphor of Sudoku to explain the complementing role of direct and mutual information. Before getting into the interpretation of these four elements within this alternative conceptual framework it is important to recall that the “timing” or better “the pace of change” of the successions across the four phases of the adaptive cycle suggested by Holling is not homogeneous. As proved by the analysis of fossil records, the evolution of life does not go in smooth trajectories of developments (a smooth commuting over the four phases). Rather the movement over these phases takes places through a series of catastrophic readjustments (i.e. the punctuated equilibrium suggested by Eldreged and Gould) that can be read using the 4 categories shown in **Fig 21**. This implies, that we should expect to find non-disturbed ecological systems operating for a long period of time without perturbation in a state of quasi-steady state (a state of CONSERVATION that prevent the phase 4 of RELEASE) and only rarely in a phase of catastrophic re-arrangement into a different metabolic pattern (obtained by re-structuring the internal identity on a new definition of boundary conditions. When this re-organization takes place, we move in between phase 1 and phase 2 – a state of EXPLOITATION due to the full realization of the phase of RENEWAL.

The interpretation of the four phases within the narrative of holons and holarchies is briefly described below. Being an endless cycle associated with a semiotic process (in which the various steps are defined by the other in an impredicative way) it is impossible to individuate an entry point that can be considered as the starting point. The establishment of a semiotic process associated with life was due to ***the combination and interaction of the various pieces of the processes co-existing simultaneously at different scale, that suddenly “made sense” of each other***. That is, the starting of the semiotic process of life, not necessarily needs to be identified with one of these step, but rather with the co-existence of conditions making it possible to define on the process side and on the information side a first semantic closure over systems of codes determining an interaction between a proto-information space and a proto-metabolic system. Then when this combination determined an autopoietic whole capable of reproducing itself and to preserve the meaning of the information recorded, reproduced, transmitted and interpreted by metabolic elements operating at the lower level we got the starting of a semiotic-process capable of expanding its domain of influence. In the analysis of the cycle I start from the lower left corner, just because of the Greek letter a written there catches the attention.

1. RENEWAL (a) – In order to have a semiotic process one must have a repertoire of validated holons, capable of expressing a metabolic pattern across different levels based on the recording and transmission of information about the “external world” according to the pattern described in Fig. 8. In the holonic interpretation this cell/element is simply referring to the repertoire of valid (viable) holons present in the system. However, this cell/element plays a key role of renewal in those situations (after a crisis of the phase of conservation) requiring to go “for something else”, in terms of organization of the metabolic pattern – exhaustion of resources and other changes in external boundary conditions.

2. EXPLOITATION (r) – Whenever the whole network is facing a situation of weak external constraints making it possible an expansion of the actual metabolic pattern at a large scale, on the process side it becomes possible re-adjustments - a redistribution of roles (functional types) within existing ecosystems. This re-adjustment led by the process side leads to a change in the relative size of the realizations of instances of structural types – and an updating of the recorded information in the NAMDED. In this situation, we should expect a selection among the existent taxonomy of validated holons. That is, this cell/element indicates that in a situation of lack of strong internal constraints generated by mutual information and a lack of external constraints leaving room for the expansion of the whole network we should expect the amplification of those local metabolic patterns that, at the local scale, are individuating and tracking the existence of external favourable gradients. An amplification of these structural and functional types makes it possible an increase of the activity of self-organization of the whole network. This is the reason why the phase of renewal (the testing of new holons) is generally associated to the phase of exploitation. When one of the available holons can expand further, it is used as an agent for restructuring

of the whole network (renewal) using a bottom-up driver of change. We can imagine that this phase is associated with the idea of colonization of new areas - the exploitation of resources not already used by other living systems or used at a lower level of efficiency. However, there is a problem with this phase: a rapid expansion implies a quick exploitation of available gradients (increasing the possibility of clashing against external constraints), and the amplification of a few winning holons creates many copies of a small set of semiotic controls. In this phase the system builds redundancy in the information space (many copies of a few holons), a situation associated with a low level influence of mutual information (from this the reference to "r selection"). In this phases we can expect a system that is accumulating "capital" – growth – using strategies more concerned with addressing the problem of how to deal with internal constraint (local information about how to improve the production and operation of structural types) rather than with addressing the existence of external limits. The autocatalytic loop associated with exploitation – the capital provides return used to make more capital that provides more return – implies that this phase does not last much. During the phase of expansion the semiotic process learn how to re-shape its internal organization and how to update the repertoire of purposes (by amplifying only those lower level holons getting a larger return) in order to become larger as soon as possible.

3. CONSERVATION (K) – After reaching external limits, the whole biological complex has to learn how to use its capital of redundancy to develop adaptability. This requires moving to a more elaborated system of controls (a diversified set of narratives relevant for a diversified repertoire of holons). This cell/element indicates the reaching of this phase. This implies that the effect of mutual information becomes stronger and stronger (this explains the reference to K-selection). The system learns about the key importance of external limits and rather than keeping expanding by assuming the winning beliefs will remain true for ever, it moves to a strategy aimed at increasing and conserving the amount of meaningful information about the TAO by boosting the diversity of purposes and beliefs. After having achieved this result, the system tends to remain in a situation of quasi-steady state.

4. – RELEASE (W) – This cell/element should be considered as the ultimate test of the semiotic process. A test that is done in the pragmatic step. In fact, in this cell/element we have the repertoire of instances of different structural elements testing the effectiveness of the existing organization. The semiotic process can have three different results at this level: (1) the instances are regularly realized within the expected pattern. This event stabilizes the entire network that remains in the phase of conservation of the existing set of essences; (2) the instances cannot be realized and reproduced and therefore the relative information is systematically removed from the recorded NAMED. This fact, destabilizes the essence of the relative holons by sending a message about the lack of validity of the information (the meaning of the information about the classes of holons whose instances do not survive can no longer be stored in the semiotic process); (3) when the stability of the semiotic process is jeopardized by a dramatic reduction of the mutual information referring to the old set of boundary conditions the metabolic network enters in crisis. Then it becomes possible for a better holon (a new structural type due to a mutation or centripetality or other causes of change) to become a new entry in the repertoire of validated essences to be amplified in a new phase of renewal. Here the option of radical openness enters into play. It should be noted, however, that this renewal will require a certain catastrophic restructuring in the network (punctuated equilibrium . . .), since several connections within the network will have to be re-structured simultaneously to generate a new mosaic effect.

6. The taming of uncertainty or "how to win when using bad models": the concept of optionality suggested by Taleb

When discussing the possible strategies that a self-organizing semiotic Sudoku should follow we saw that in a semiotic process used to learn about the validity of the information about "the self" it is impossible to fully verify the validity of the beliefs used by lower level elements. Another sophisticated explanation about the impossibility of using perfect anticipatory systems has been given by Robert Rosen (1985) using the drawing shown in **Fig. 22**. Let's imagine that two fortunetellers play chess using their crystal ball. If one of the two would perform better due to a better crystal ball he will win systematically all the games and therefore it would be not possible to keep alive a championship. Assuming that both of them would have a completely reliable crystal ball it would impossible to anticipate the move of another system that is at the same time anticipating your move. In order for the two people depicted in Fig. 22 to make a move and play against each other for a long period of time, they must have a certain level of uncertainty in the reciprocal predictions about each other moves, they must have wrong anticipatory models . . .

This theoretical discussion about the need of having uncertainty in life is certainly not needed by individual instances of organism trying to survive in the external world. Living systems, especially individual instances of organisms, very rarely suffer for an excess of reliable information about their future! Life by definition if about surprises and a continuous becoming. Therefore if it is true that information in life is validated by physical processes trying to achieve a given set of purposes using anticipator models, it is also true that these models are by default all wrong. So before closing this essay I discuss a recent explanation given to the fact that in spite of the weakness of anticipatory models, life is after all, quite effective in producing and preserving meaningful information used in its own semiotic process. This explanation is provided by the concept of Optionality, proposed by Taleb in his book "the Antifragile" (2012). This concept refers to the possibility of "tinkering," at a moderate cost trying to make changes to existing conditions, while having the possibility to achieve unlimited pay-offs in the case the tinkering will result successful. According to Taleb this is the only winning strategy to be adopted when facing an unavoidable large dose of uncertainty, when you cannot rely on anticipatory models. Again, I am providing here an explanation of the mechanism of optionality that is based on the concept of holons used in a semiotic process. Within this framework *optionality* in life works in this way: on the process side (in the TAO) stochastic events can result in mutations to individual realizations of holons. Due to the mechanism of replication of DNA any stochastic change leaves a temporary record in the instances that it is expressing it. Like the recorded videos of security cameras, if this information is neither relevant nor useful it will be just deleted without using it: if the tinkering is unsuccessful, then the loss is minimal. The information affected by mutation becomes a corrupted copy of something – a structural type - that in any case is protected by redundancy – since a species is an equivalence class of organisms a defective instance is not a problem. That is, on the process side, you just lose an individual organism at the local scale. On the other hand, on the information side (in the NAMED) if life gets lucky she can win the lottery – i.e. getting a new winning structural/functional type that can be amplified across scales in the processes taking place in the TAO: western economies sucking out more and more oil from the ground arriving to rule the entire planet (at least for a while). On the information side (in the NAMED) types do not have scale, meaning that if biophysical conditions are favorable a new "winner" can spread its domain of influence across biophysical processes operating at different scales affecting the mutual information across many levels of organization. If a "new holon sheriff" appears in town the others will have to shape in or shape out. This is how life ranks things according to optionality within the integrated set of constraints represented by the Sudoku. The take-all winners can erase a lot of numbers already written in it and/or force a re-adjustment of the rules of the game. The incredible power of optionality is generated by the issue of scale: individual realizations - on the process side - are scaled, whereas types - on the information side – are, by definition, out of scale. Therefore, losses are limited to the scale at which the tinkering is done on specific incumbents operating in the TAO, whereas the gains do not have limits depending only to the biophysical limits of expansion of the patterns associated with the new type in the NAMED: a new colony of cyanobacteria born at the level of the micron can colonize a whole planet and change its atmosphere!

7. So what? What is life? Did we gain any insight from all of the above?

Margalef describing the organization of an ecosystem that he consider as "a channel which projects information into the future (1968, pag 17) makes a distinction between different types of channels of information: "*one is the genetic channel in replicable individual structures. Another is a truly ecological channel based on the interaction between different cohabiting species and expressed in the relative constancy or in the regular changes of their number. This channel is the one continuously referred to in this book. A third channel can be called "ethological" (because 'ethology' is the science of animal behavior); it transmit what has been learned by individual activity and experience and it is transmitted to future generations outside the genetic channel. This last channel had a negligible importance at the beginning of life, but it is now increasing explosively. In it can be placed: formation of trails and burrows that are used by other individuals, accumulation of dead material, imprinting, imitative collective behavioral memory and formation of local tradition, and the legacy of tools and all cultural manifestations in man*". (1968 pag. 97-98)

The possibility of learning new and new ways to establish more sophisticated semiotic processes taking place across different scales (from microns to thousands of miles) requires the continuous creation of codes establishing a bridge between recorded information and physical process to which the semiotic process can assign meaning when using the information for control. Marcello Barbieri has defined this process of creation and use of new codes to enhance the effectiveness of semiotic processes as *codepoiesis*. This concept is of extraordinary importance to explain the evolution of life (especially when considering the evolution of human knowledge and technology) since codes can establish relations among domains completely unrelated in terms of scale and dimensions. Codes can establish new expected relations across elements of sets defined in totally logically independent domains – a bunch of letters – "LONDON" the objective language – can be associated to a bunch of infrastructures and people living in a given place – London the metalanguage made of thermodynamic processes. Therefore codepoiesis is essential in allowing the establishment of coherent metabolic patterns expressed, reproduced, and controlled in processes arising simultaneously across different scales (from molecules to organisms to biomes to the entire planet). If life is matter with meaning, if we want to study life we have to learn how to observe also things that are not physical objects. We have to learn how to study the mechanisms making it possible to generate and assign meaning. In relation to this point, what I presented in this essay is an effort to prove that in last analysis, codepoiesis is what makes life unpredictable and possible in the first place.

References

Mayumi, K. and Giampietro, M. 2004. Entropy in ecological economics. In: J. Proops and P. Safonov (Eds.), *Modeling in Ecological Economics.* Edward Elgar, Cheltenham (UK), pp. 80-101.

Giampietro M and Mayumi K. 2008 Jevons' paradox: the evolution of complex adaptive systems defies scientific analysis In Polimeni, J., Mayumi, K., Giampietro, M., and Alcott, B. *Jevons' Paradox: the Myth of Resource Efficiency Improvements.* Earthscan Research Edition, London, 192

Example: Death of a particular person

Explanation	Associative context	Time Horizon
"Humans must die"	Theoretical discussion on sustainability	LARGE
"Heavy smoker"	Meeting at the Ministry of Health to discuss new taxes on cigarettes	
"Lung cancer"	Admission into a hospital for treatment	
"No oxygen to the brain"	Emergency Room	SMALL

Fig. 1 The co-existence of non-equivalent explanations of a given event

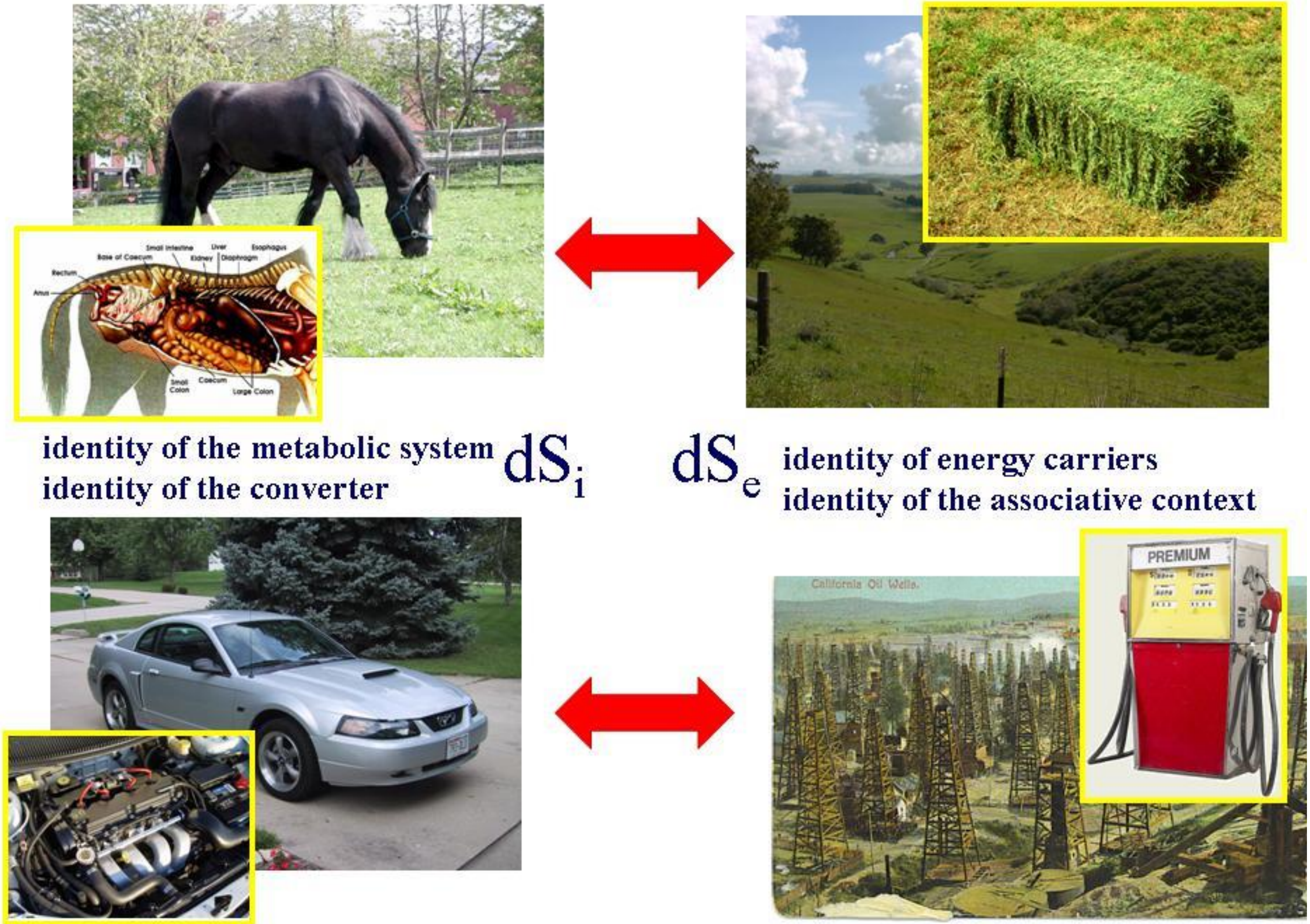


Fig. 2 The expected relations between: (i) internal view (left) - characteristics of parts/whole; and (ii) external view (right) – characteristics of the negentropy flow/boundary conditions

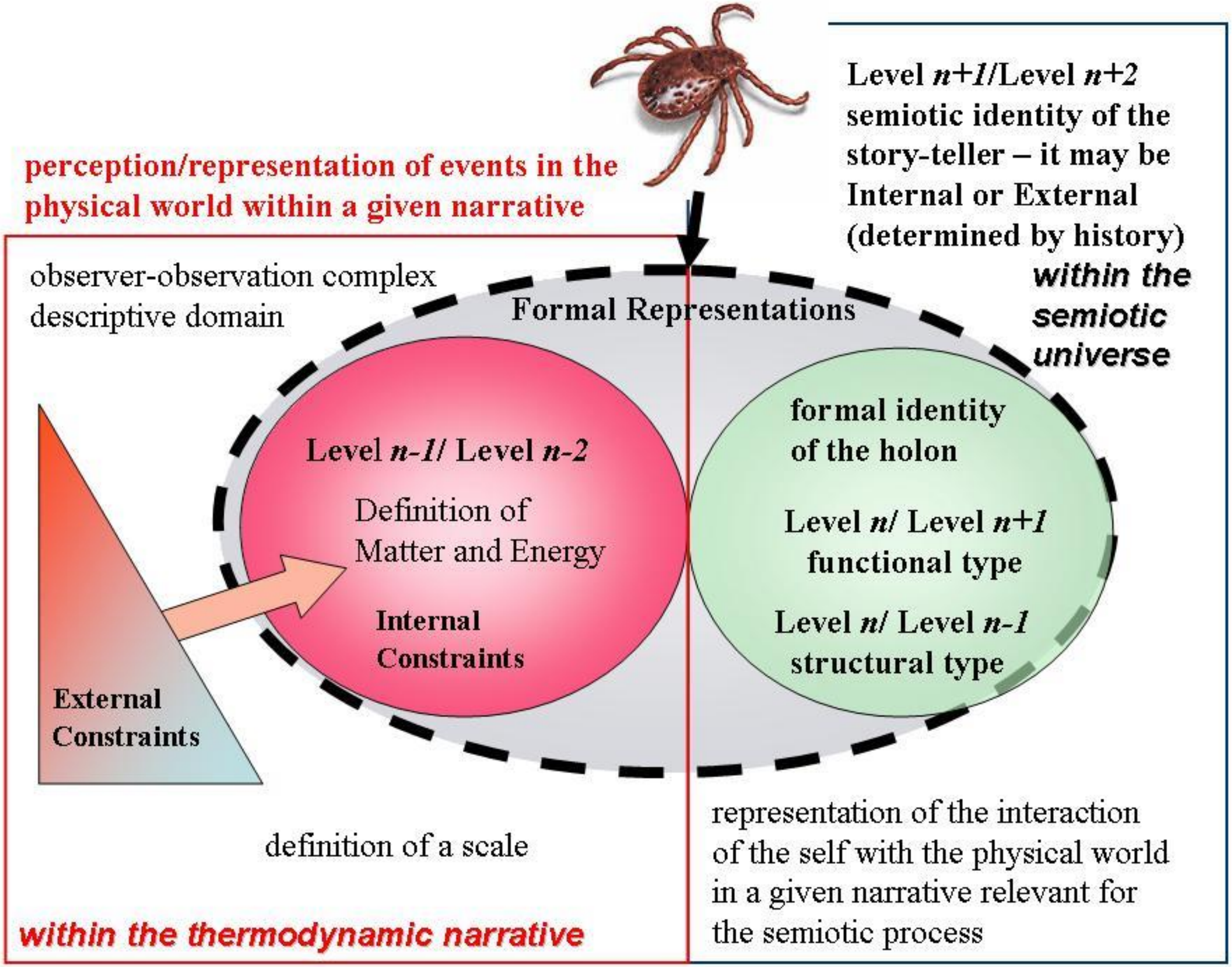


Figure 3 The representation of the relation of the three components of the holon-tick: (i) the instance (on the top); (ii) the definition of the structural type (associated with the genetic information); (iii) the definition of the functional type (determined by the thermodynamic constraints associated with the boundary conditions)

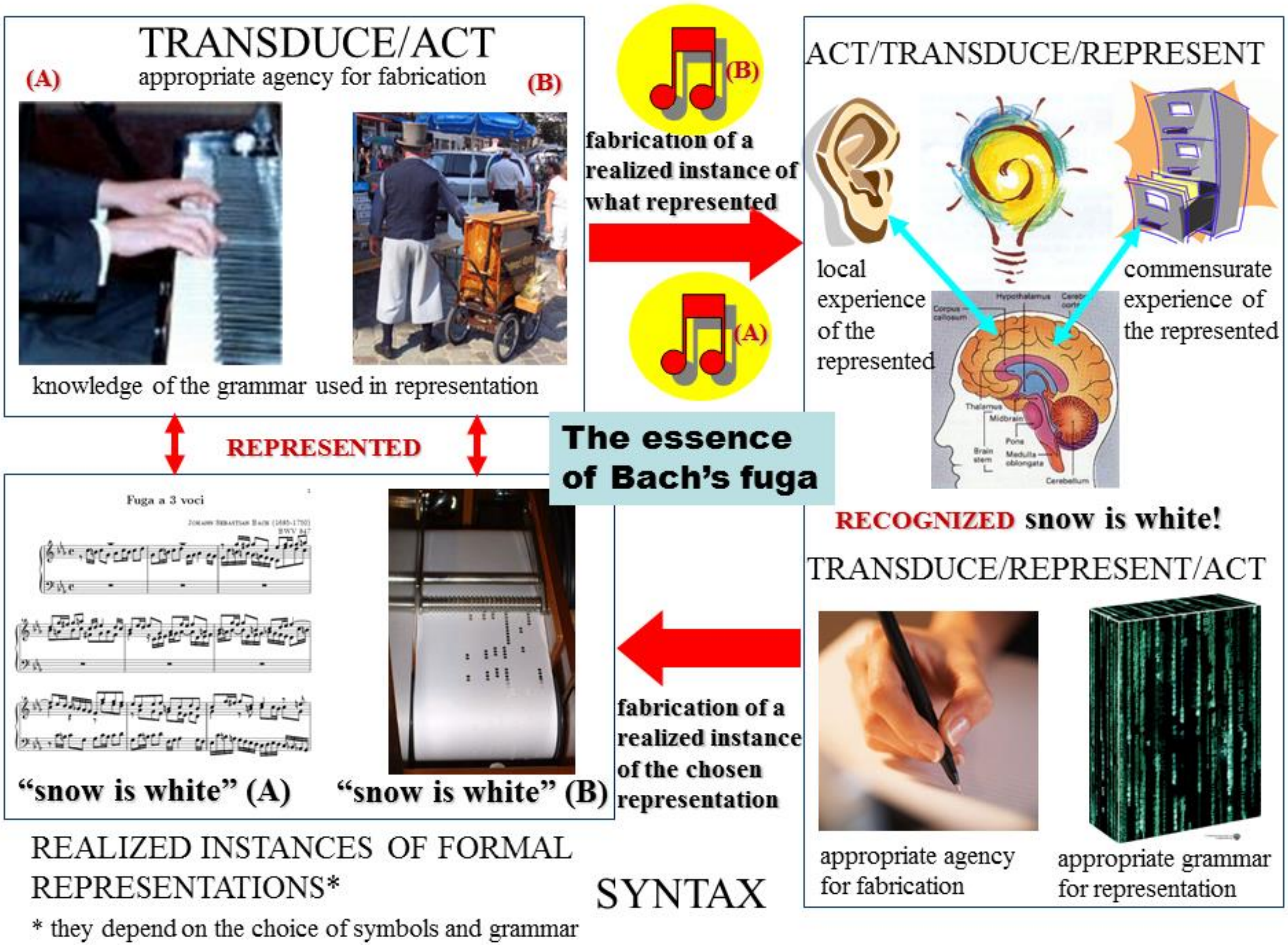


Fig. 4 – The various steps of the process of reproduction of the essence of a Fuga of Bach

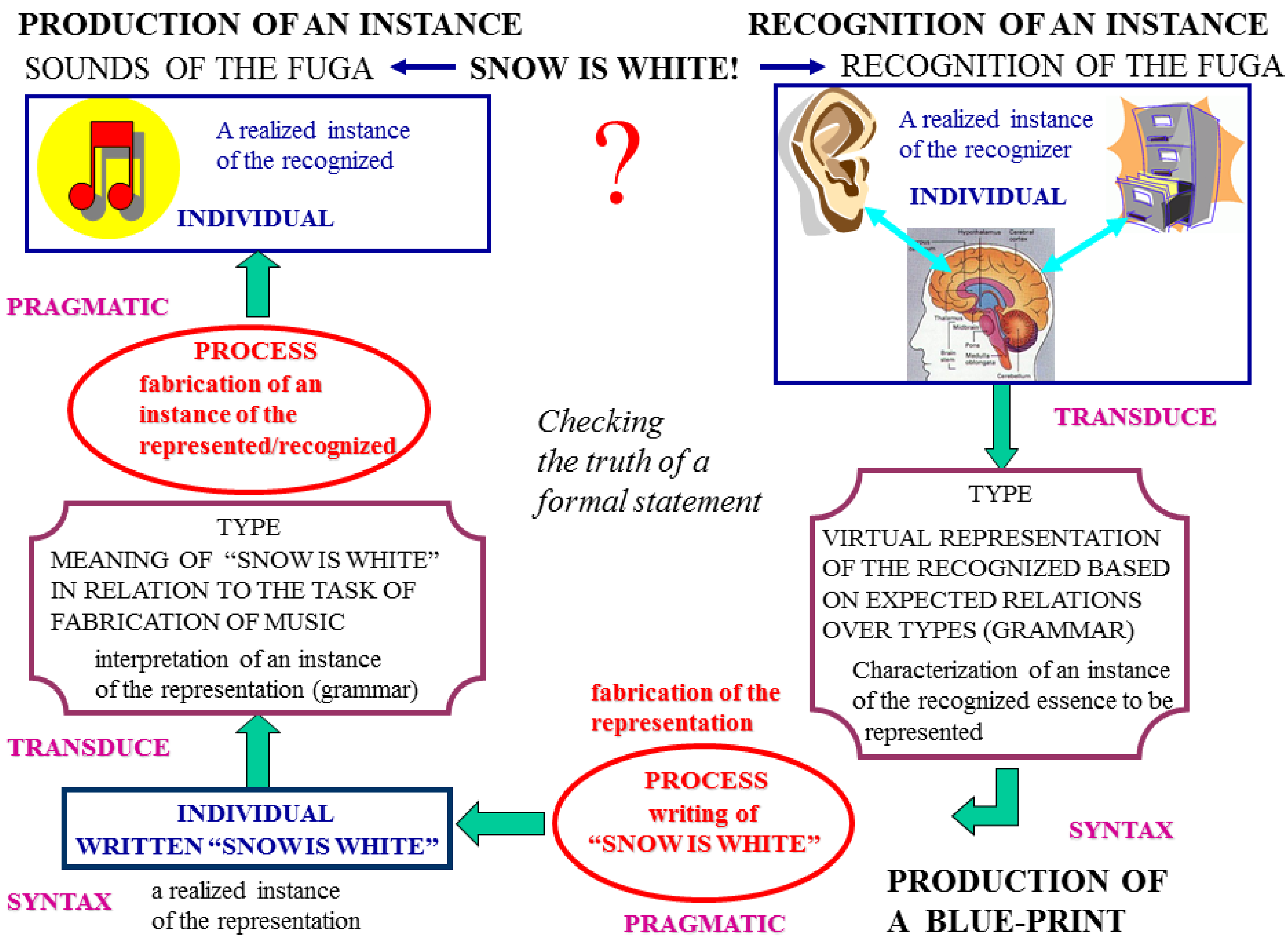


Fig. 5 – The steps of the semiotic process in the reproduction of the essence of a Fuga of Bach

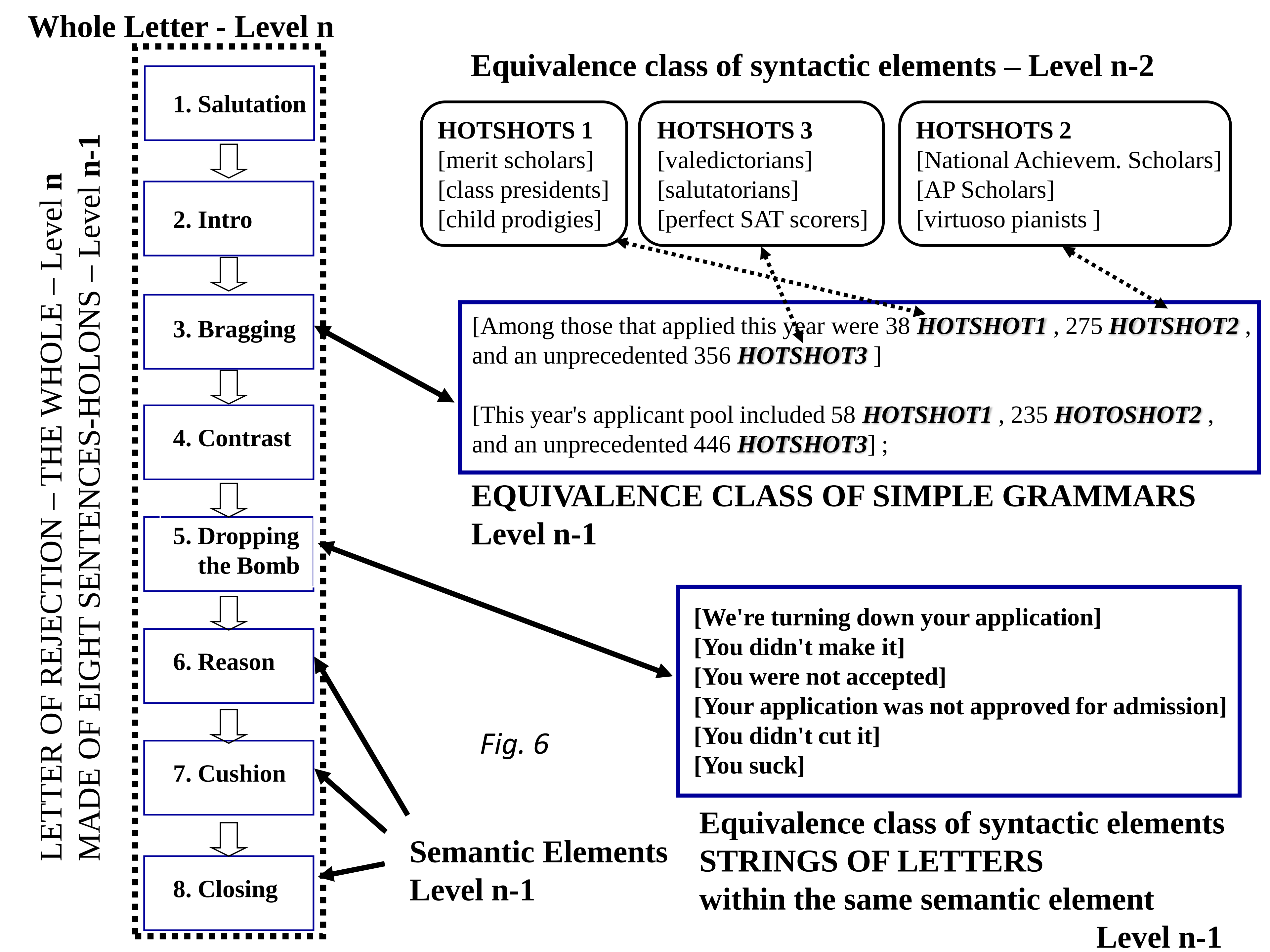

Whole Letter - Level n
LETTER OF REJECTION – THE WHOLE – Level n
MADE OF EIGHT SENTENCES-HOLONS – Level n-1
1. Salutation
2. Intro
3. Bragging
4. Contrast
5. Dropping the Bomb
6. Reason
7. Cushion
8. Closing
Equivalence class of syntactic elements – Level n-2
HOTSHOTS 1
[merit scholars]
[class presidents]
[child prodigies]
HOTSHOTS 3
[valedictorians]
[salutatorians]
[perfect SAT scorers]
HOTSHOTS 2
[National Achievem. Scholars]
[AP Scholars]
[virtuoso pianists]
[Among those that applied this year were 38 HOTSHOT1 , 275 HOTSHOT2 , and an unprecedented 356 HOTSHOT3]
[This year's applicant pool included 58 HOTSHOT1 , 235 HOTOSHOT2 , and an unprecedented 446 HOTSHOT3] ;
EQUIVALENCE CLASS OF SIMPLE GRAMMARS
Level n-1
[We're turning down your application]
[You didn't make it]
[You were not accepted]
[Your application was not approved for admission]
[You didn't cut it]
[You suck]
Semantic Elements
Level n-1
Equivalence class of syntactic elements
STRINGS OF LETTERS
within the same semantic element
Level n-1

Fig. 6

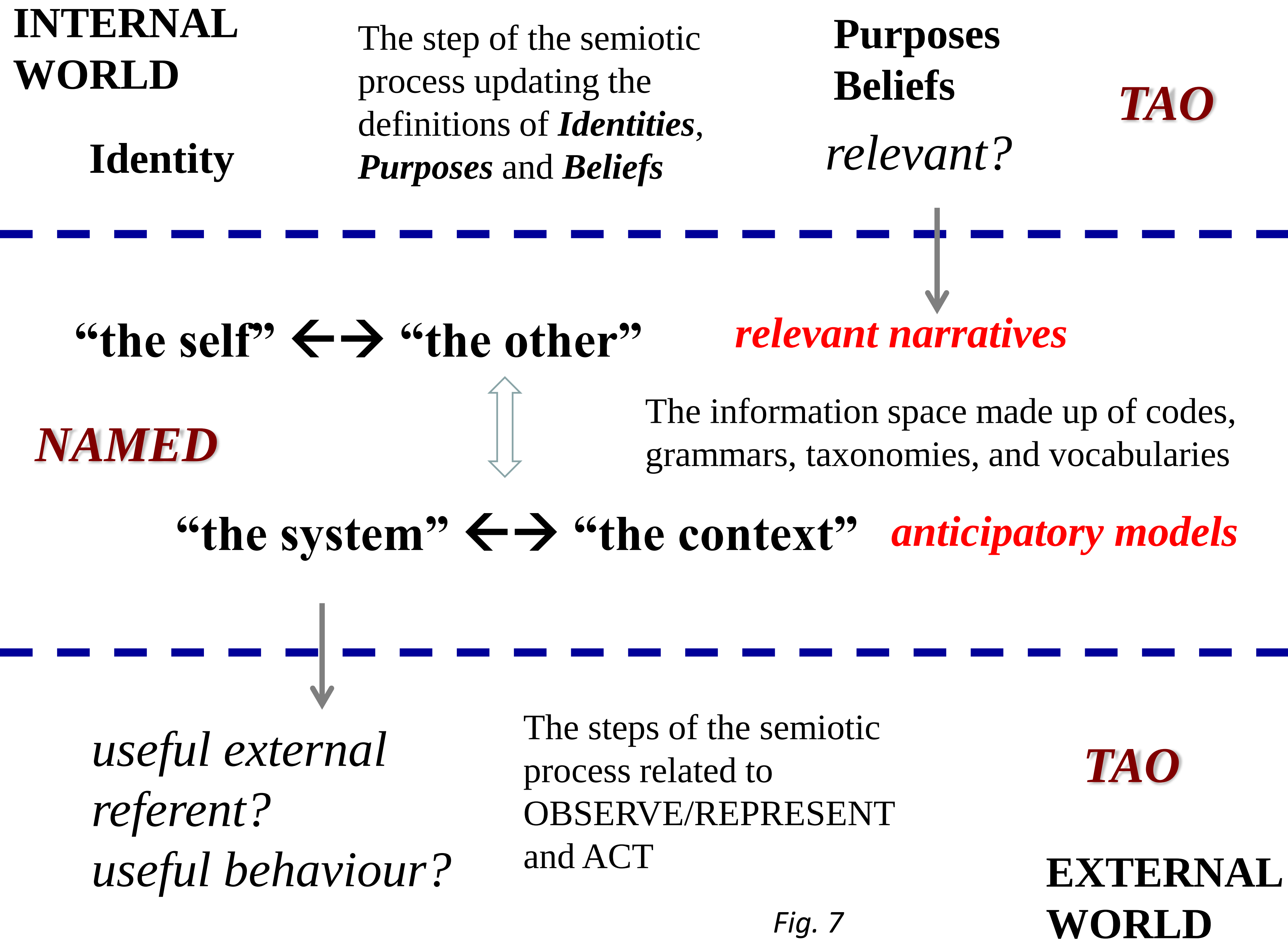

INTERNAL WORLD
Identity
The step of the semiotic process updating the definitions of *Identities*, *Purposes* and *Beliefs*
Purposes
Beliefs
relevant?
TAO
"the self" ←→ "the other"
relevant narratives
NAMED
The information space made up of codes, grammars, taxonomies, and vocabularies
"the system" ←→ "the context"
anticipatory models
useful external referent?
useful behaviour?
The steps of the semiotic process related to OBSERVE/REPRESENT and ACT
TAO
EXTERNAL WORLD

Fig. 7

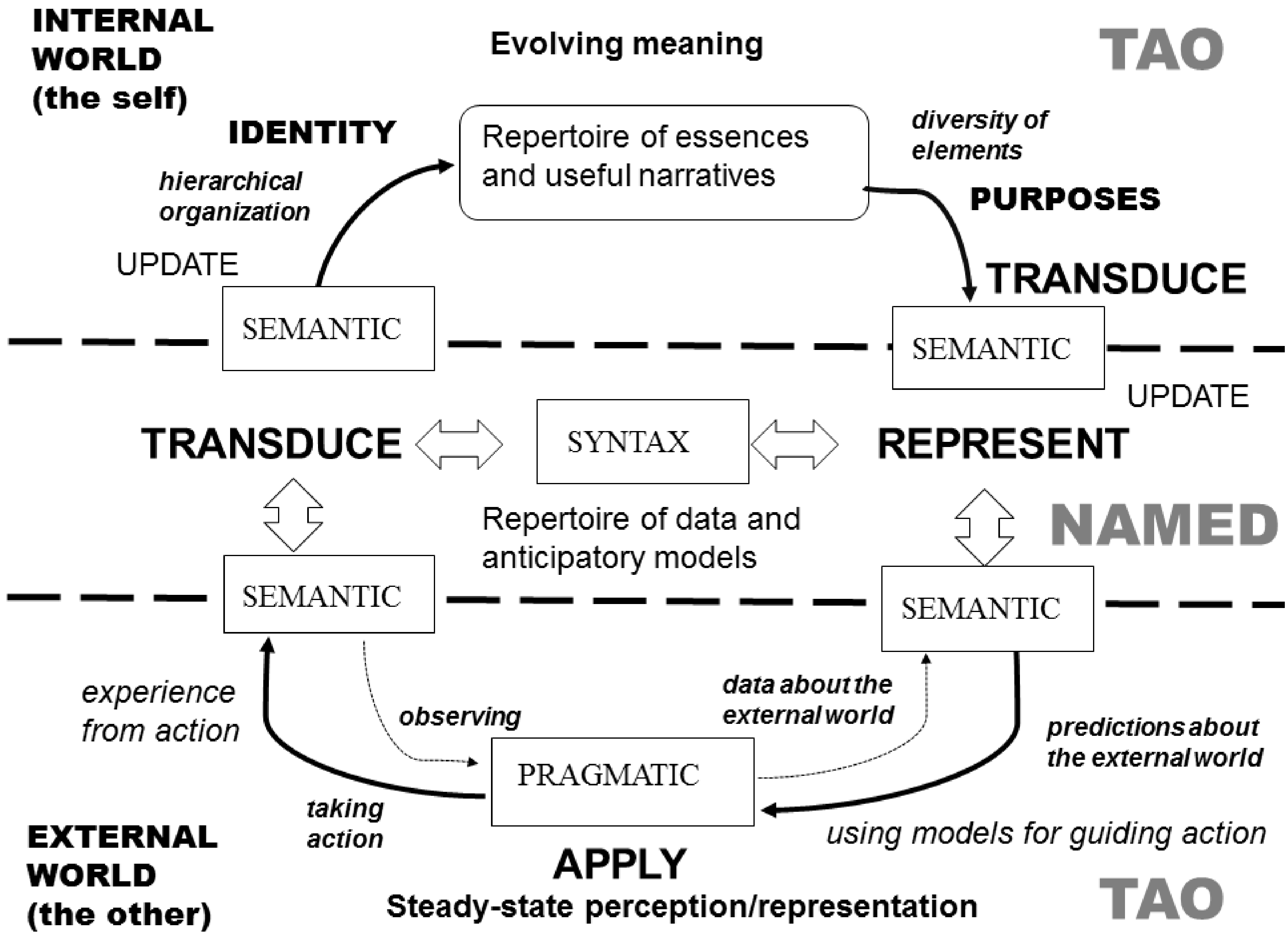


Fig. 8 An overview of the semiotic process associated with life seen as a commuting between the TAO and the NAMED (inside and outside the self)

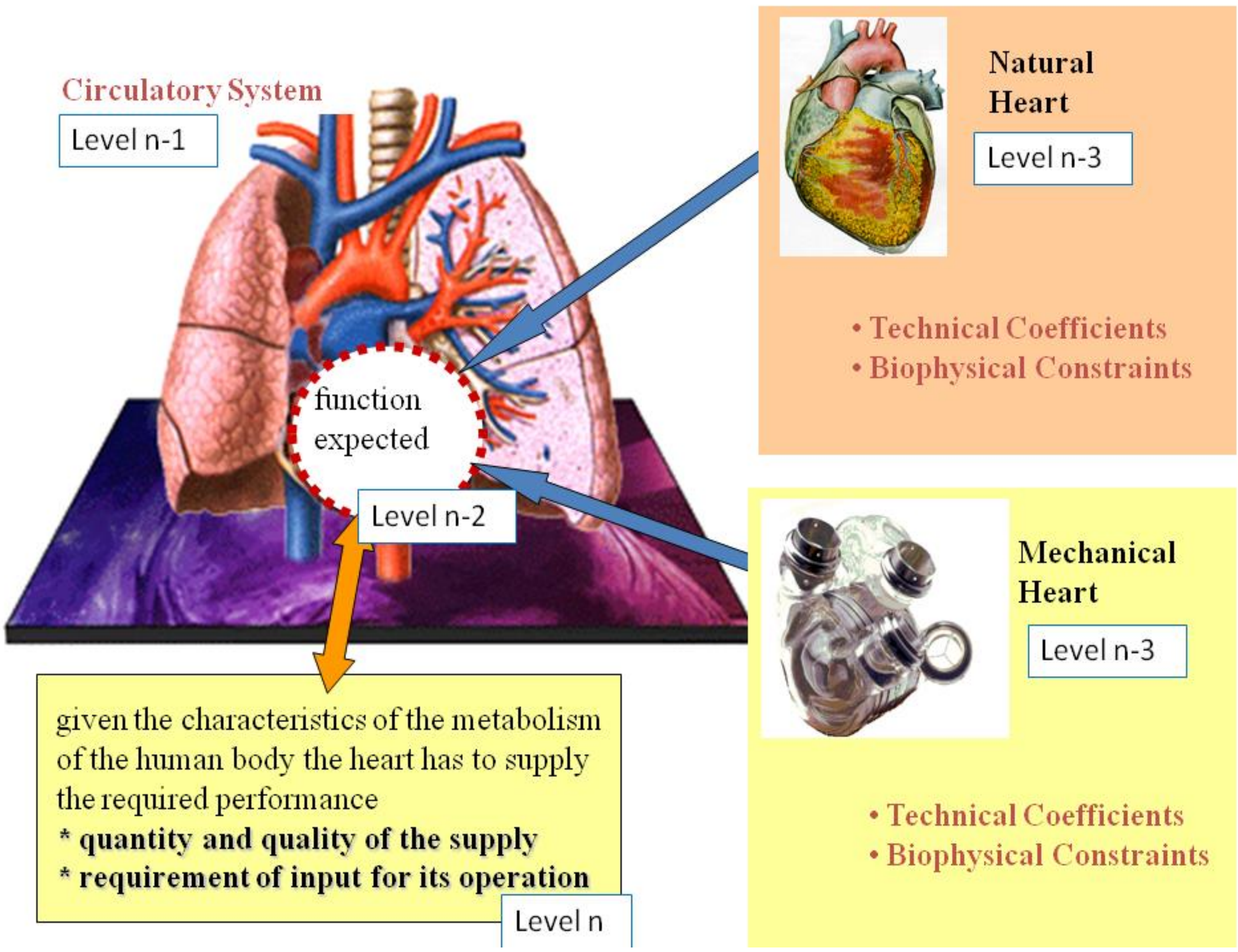


Fig. 9 A representation (based on abstractions) of organs within the human body

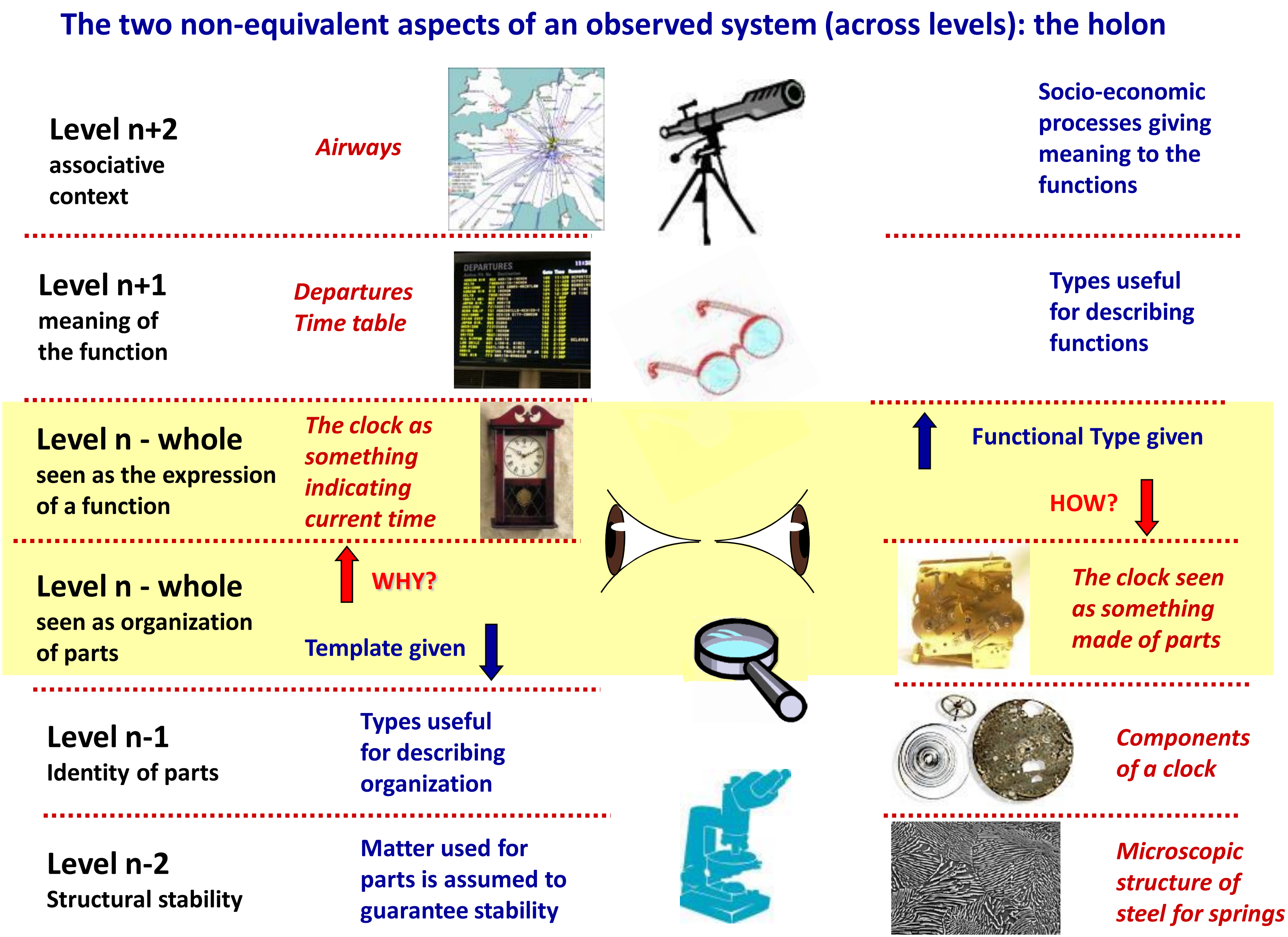


Fig. 10 The mismatch of scale when looking at the information relevant for WHAT/WHY and the WHAT/HOW in relation to a clock

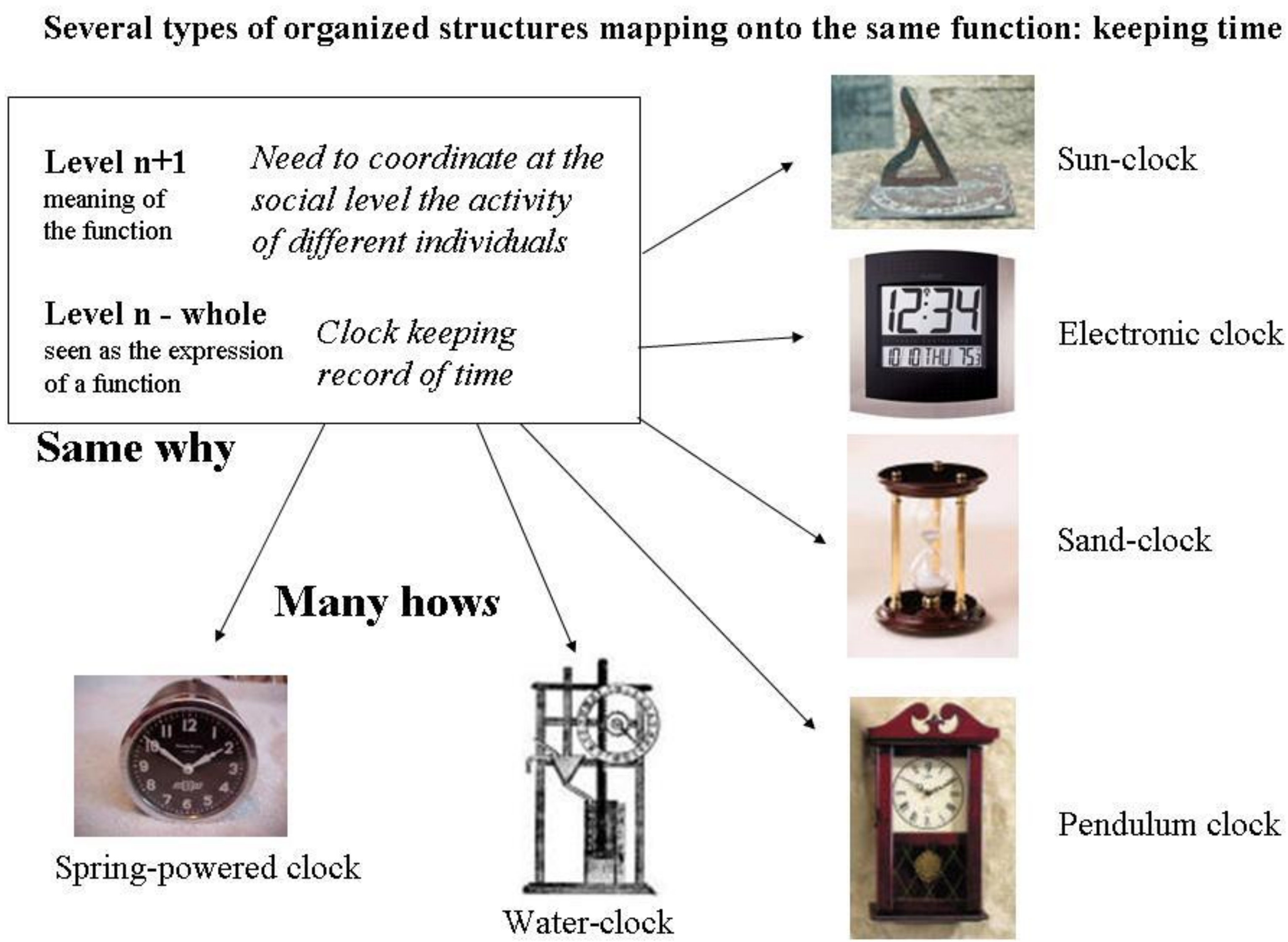


Fig. 11 Examples of many-to-one and one-to-many couplings of structural and functional types (from Giampietro et al. 2006)

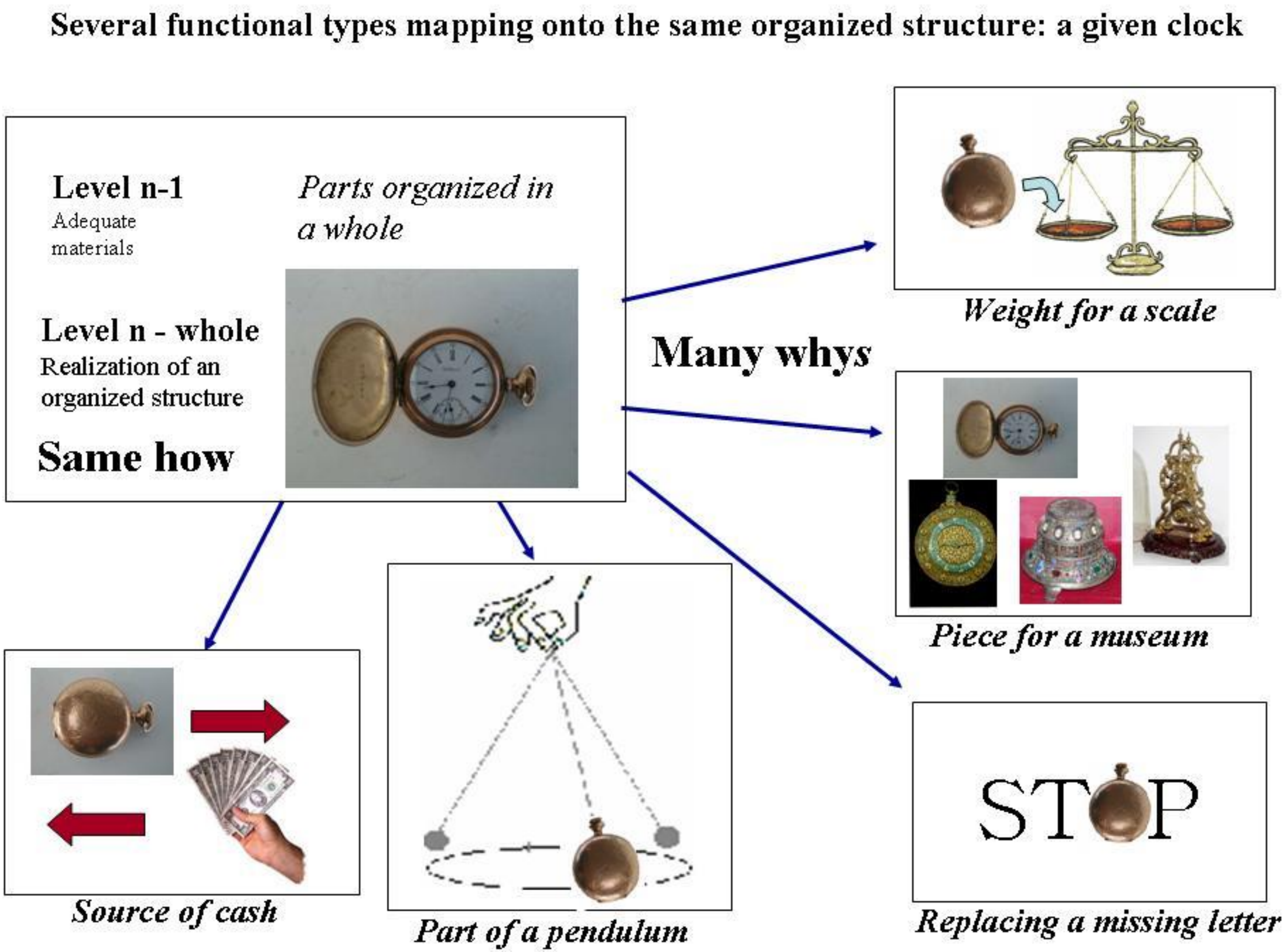


Fig. 12 Examples of many-to-one and one-to-many couplings of structural and functional types (from Giampietro et al. 2006)

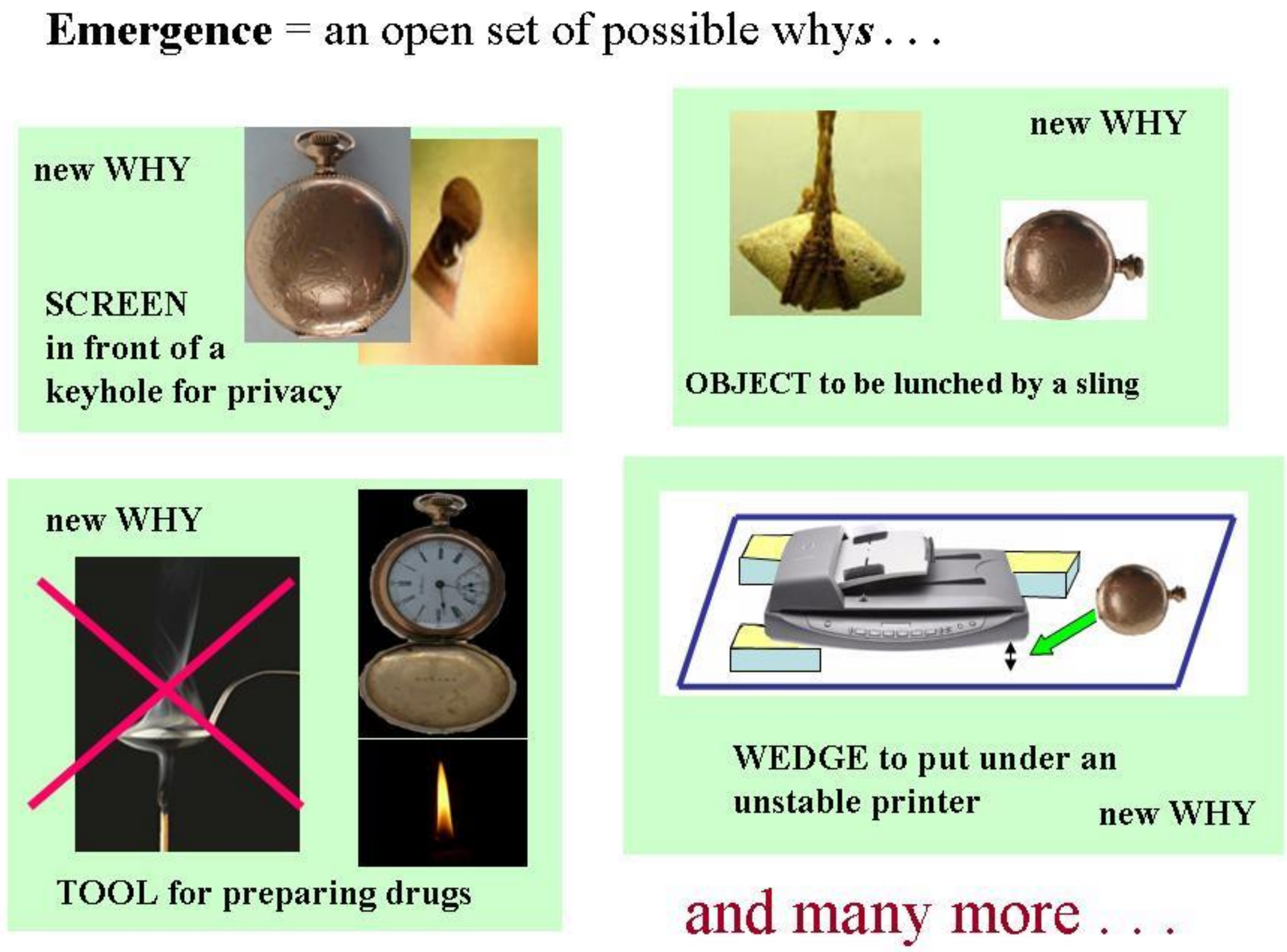


Fig. 13 Situations in which the context makes it likely the emergence of a new holon (from Giampietro et al. 2006)

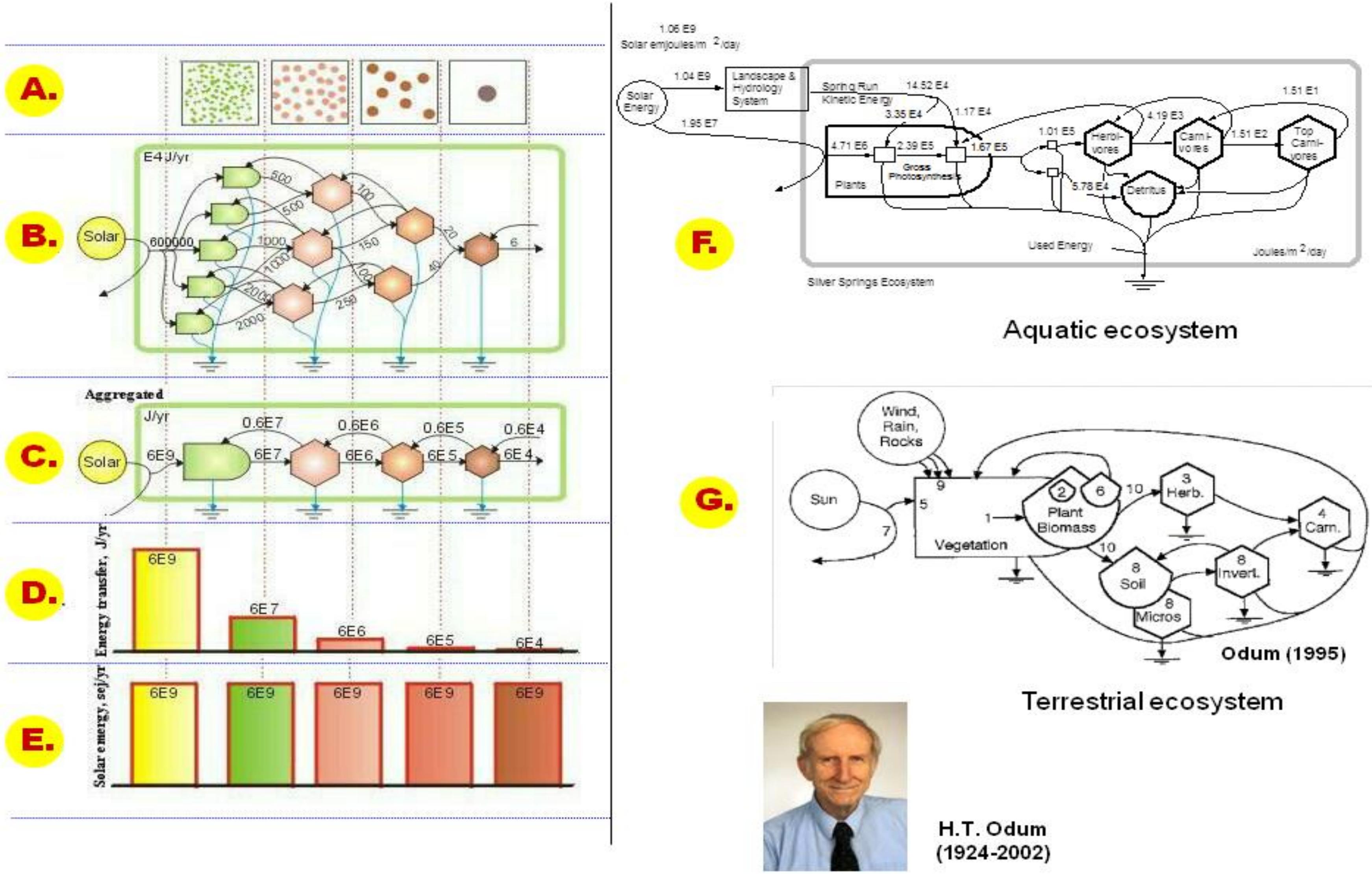
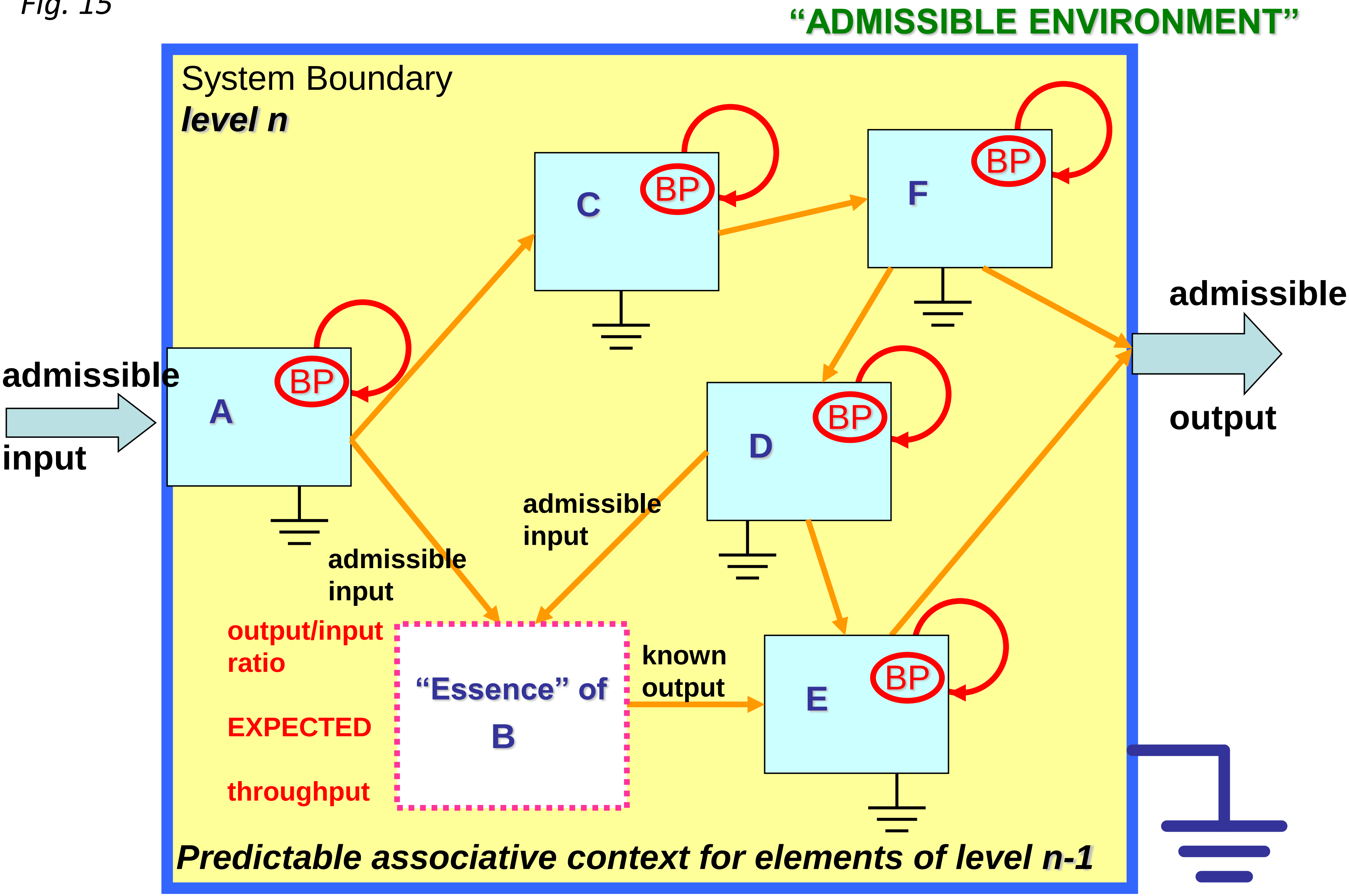


Fig. 14 A representation of the metabolic pattern of ecosystem (described in terms of fund and flow elements) and expected characteristics described as fund/fund ratios and flow/fund ratios

Fig. 15



Definition of an image of an "essence" using a mosaic effect across scales

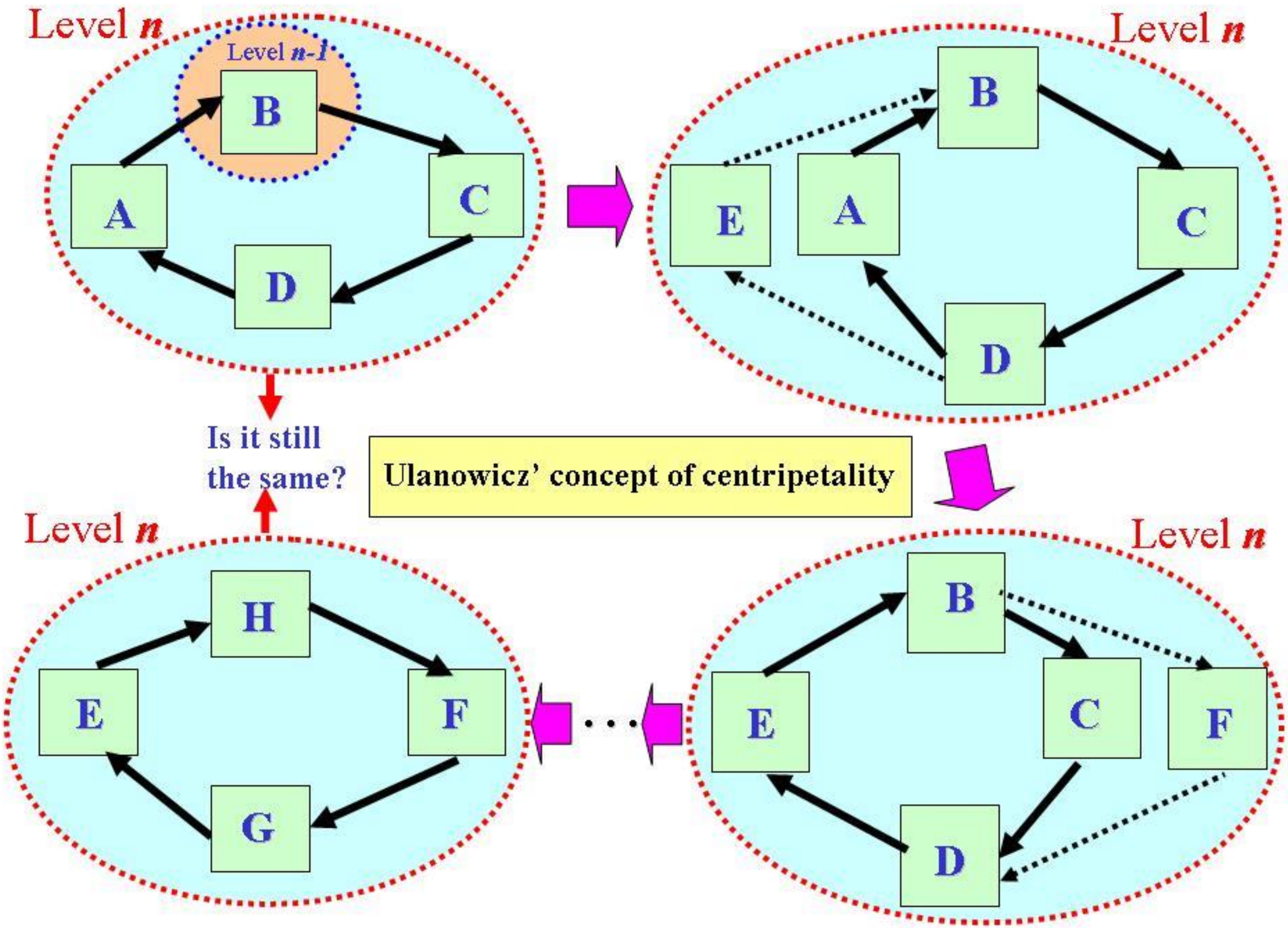
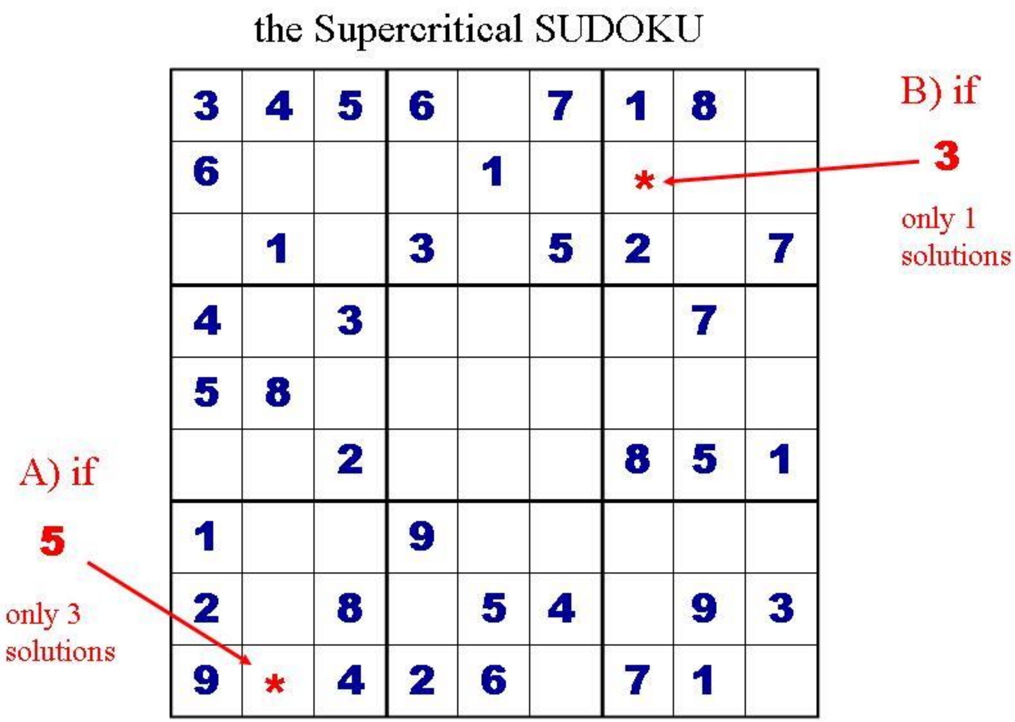
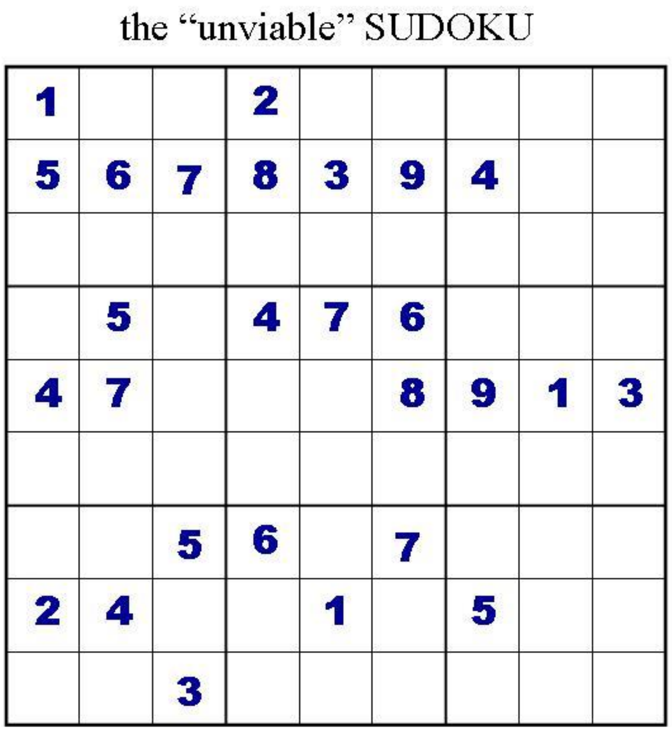


Fig. 16 Graphs explaining the concept of Centripetality





This is not a deterministic system.
This *sudoku* can have 4 different solutions.

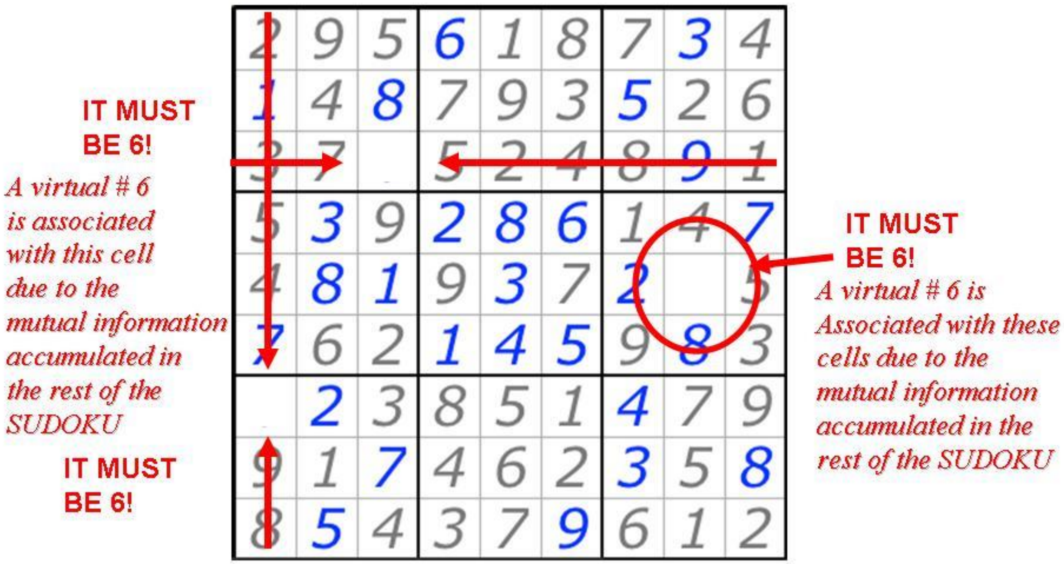
This is not a viable system.
This *sudoku* cannot have solutions.

However, the more valid information is entered (generating an accumulation of history) the more the required congruence over multiple constraints increase its degree of determinedness.
After the two steps – A) and B) – illustrated in the graph above, this *sudoku* becomes subcritical

The incompatibility between the constraints associated with "upward causation" (characteristics of the elements determining its history) and "downward causation" (cross-level constraints) entails that this *sudoku* will never make it . . . It will be aborted.

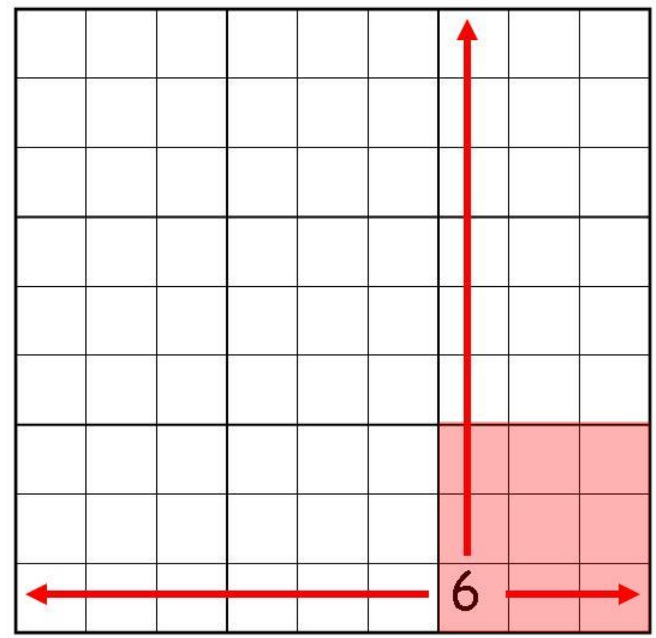
Fig. 17 Two types of sudoku

SUDOKU - "Downward Causation"



The very high level of organization of the internal structure of the system, after reaching a state of maturity, implies a strong set of constraints on the possible structural and functional types to be expressed: shape in or shape out!

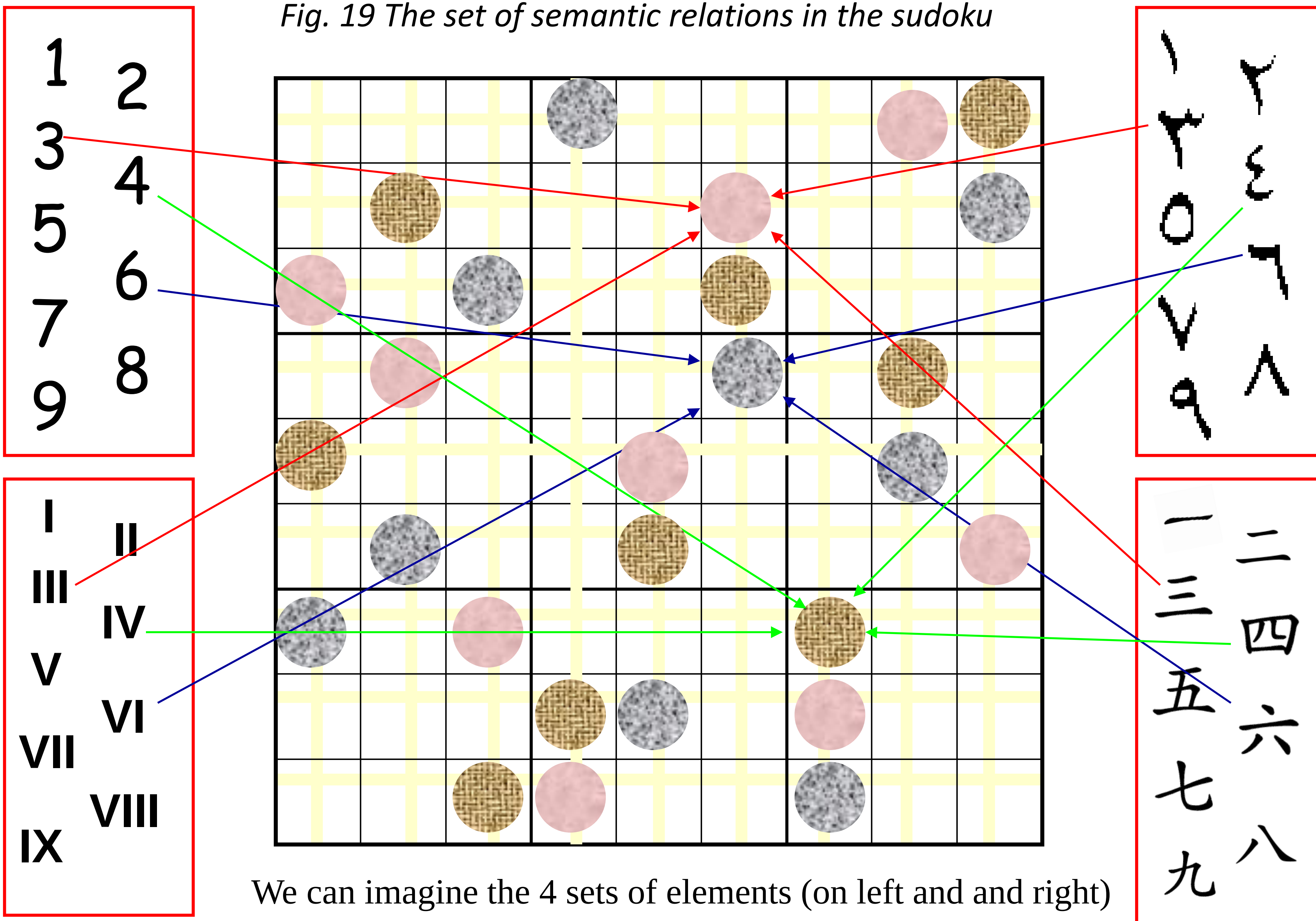
SUDOKU - "Upward Causation"



The "survival of the first" effect – in an early stage of colonization it is important to establish it-self as soon as possible, since this will dictate the conditions of entrance for the others

Fig. 18 Two types of Sudoku explaining Downward causation (subcritical) and Upward causation (supercritical)

Fig. 19 The set of semantic relations in the sudoku



We can imagine the 4 sets of elements (on left and and right) as symbols indicating metabolic elements expressing different definition of $\mathbf{dS_i}$ and $\mathbf{dS_e}$ in a dissipative network

C.S. "Buzz" Holling

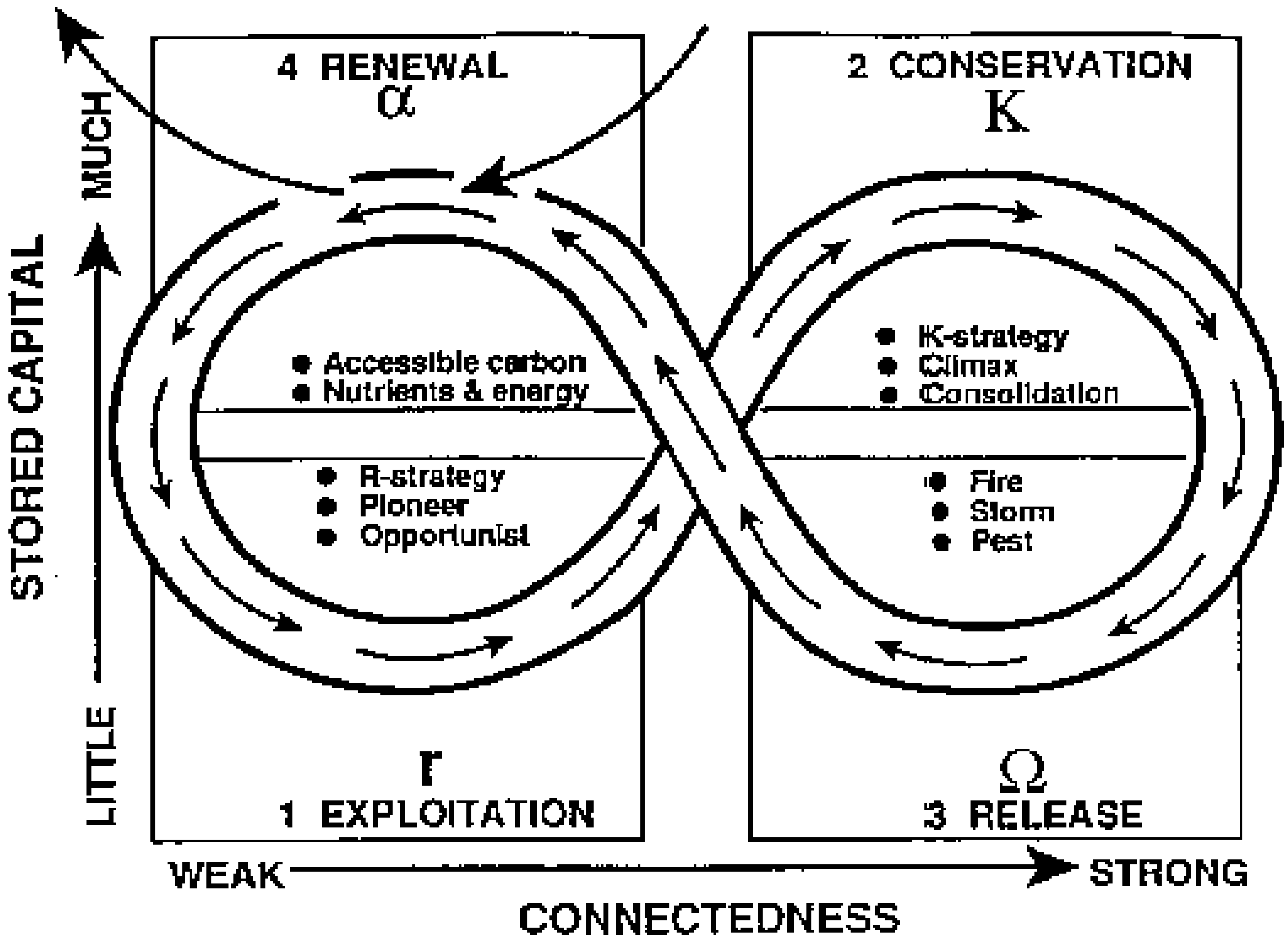


Fig. 20 The original version of the Adaptive Cycle as proposed by Holling

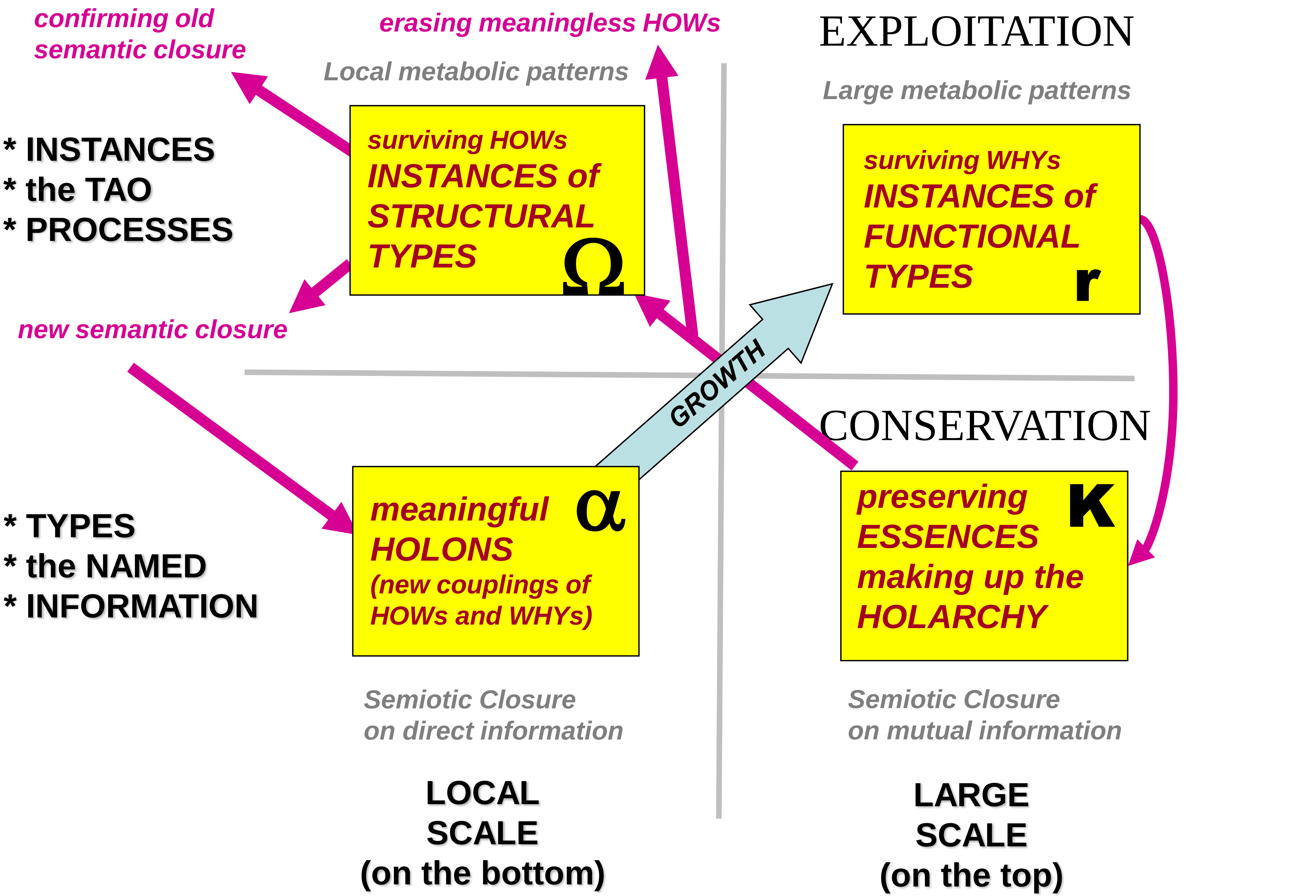


Fig. 21 The explanation of the adaptive cycle using the concepts of the holon/holarchy

The logical impossibility of a stable interaction in time between perfect anticipatory systems

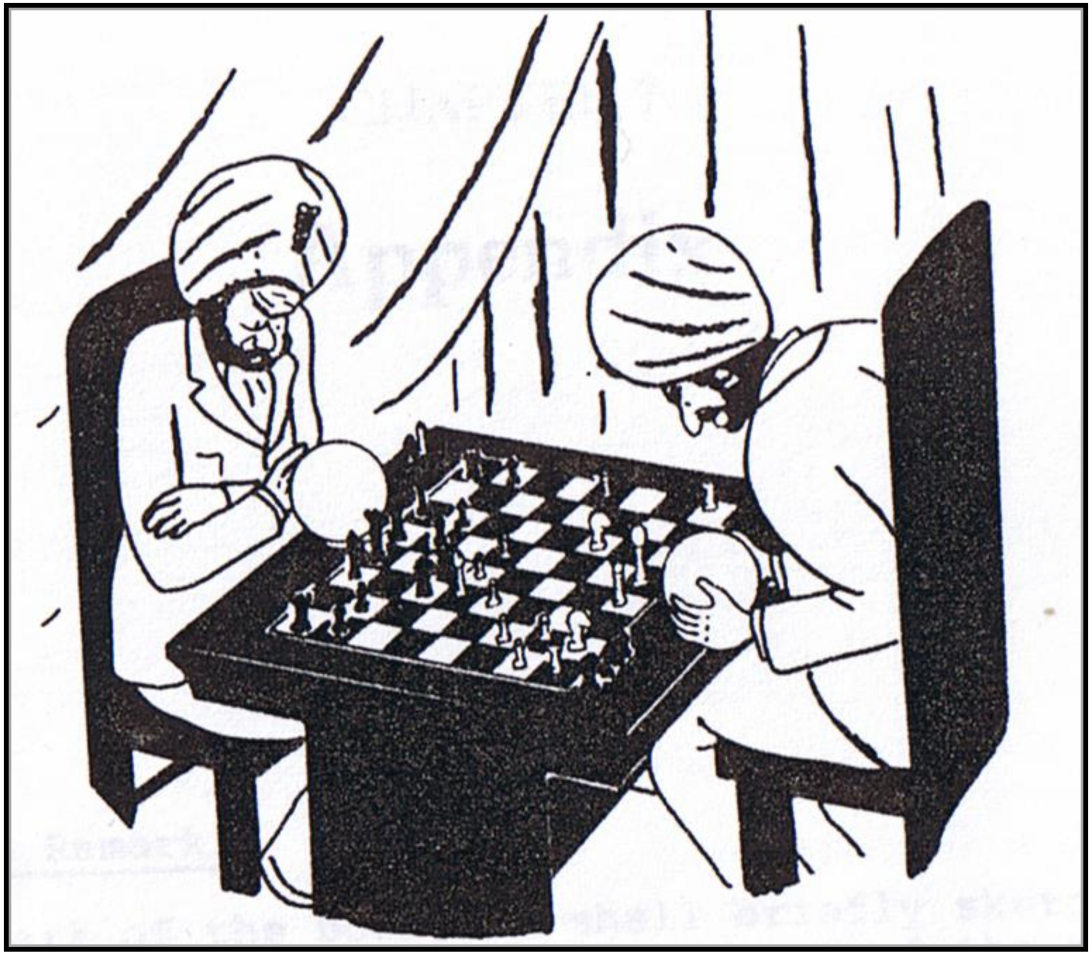


Fig. 22

Taken from: *Anticipatory Systems* – Robert ROSEN