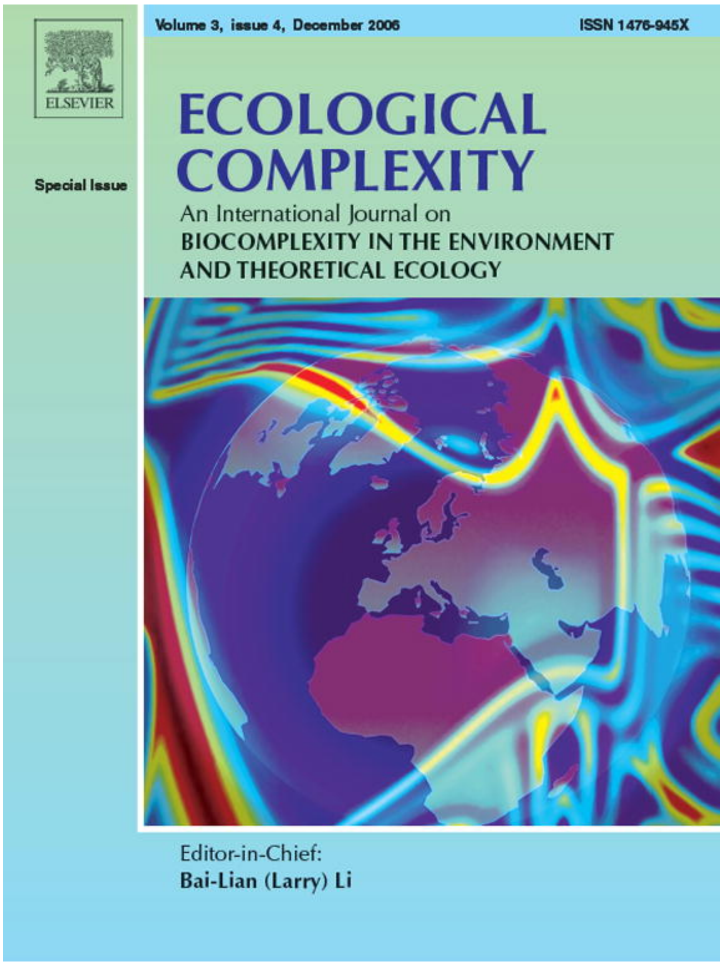
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The epistemological predicament associated with purposive quantitative analysis

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ABSTRACT

This paper discusses the epistemological predicament associated with the formal modeling of the behavior of complex adaptive systems. This is a class of systems which: (i) express functions and structures on multiple levels and scales; and (ii) become "something different" in time, because of evolution.

The paper addresses four points. (#1) The pre-analytical definition of "what is observed and how" is essential in determining any quantitative output of mathematical models. Scientists have to learn how to acknowledge and to deal better with the fact that the observer always affects what is observed when defining the descriptive domain. This influence of the observer occurs even before there is interaction with the observed in the process of gathering empirical data. (#2) The peculiar human ability to share a commensurate experience involves the concept of semiotic identity. The generation of knowledge is possible only because of the co-existence of a semiotic reality and physical systems. (#3) The special organization of living systems depends on their ability to establish and maintain a semiotic coupling between functional and structural types. This coupling is associated with the concept of *holon* and explains why it is impossible to formalize in substantive terms organizations recognized as holons. Holons can only be handled in semiotic terms. (#4) A strong semiotic identity entails an uncontested selection of an appropriate sampling procedure for validating the choice of the formal identity used in the model. On the contrary, a weak semiotic identity entails a tautology in the modeling relation. The formal identity used to represent the semiotic identity in the model has also to be used to decide about the relative sampling used for validation. The distinction between strong and weak semiotic identities places a limit on the power of modeling. A sound modeling relation requires strong semiotic identities, whereas the typical issues associated with science for governance imply perceptions and representations based on weak semiotic identities.

1. Introduction

There is an emerging literature on complexity, *Ecological Complexity* being one of the major repositories. It is much concerned with power laws and various formal systems of inference useful for quantifying complexity, a worthy endeavor. While the complexity of the pattern of avalanches in sand piles (Bak et al., 1987) do have some bearing on complexity,

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and it is remarkable that so many biological systems follow also power laws, the semantic and semiotic aspects of biological and social complexity is clearly missing from this analysis of complexity. An essential tension in complexity arises between alternative levels of observation and analysis. There are explicit decisions underpinning the choice in level of analysis, with purpose and meaning playing roles. Whereas simple physical systems may be well understood as simply behaving in a thermodynamic fashion, we cannot understand biosocial systems without invoking meaning and privileged positions at some level. Once we take meaning and significance as essential players in understanding biosocial complexity, the role of narrative and the choices of the observer/story-teller needs dissection. A foundational device in all of science is modeling, and in this paper we will work our way through an analysis of the process of creating and calibrating models, particularly in the context of complexity in biological and social systems.

In this paper we claim that the role of the observer/story-teller is more central than we had originally thought. Scaling and hierarchy theory are the points of departure. We quickly move on to address a problem that arises when sharing the meaning of symbols used for storing commensurate experience. This requires assigning a formal identity to what is observed and perceived in terms of a semiotic identity. Koestler's (1968) notion of holon occupies a central position in the discussion. The holon concept leads us to the distinction between models (based on a strong semiotic identity) and similes (based on a weak semiotic identity). Strong semiotic identity is addressed in formal models, where empirical observations tied to the model are seen as equivalent except for the scale. In weak semiotic identity there is a tautology, where the formalization adopted in the model is used to suggest how to make the observations. In relation to this point we briefly introduce the theory of modeling relation developed by Rosen (1985, 1991), which is discussed in terms of a coupling between a semiotic and a formal identity assigned to the modeled system. In the end, we are satisfied that strong versus weak identities are the critical points of distinction, which are generally overlooked by modelers when science is used for governance.

Any formal analysis – e.g. scientific model – must start with a given perception and representation of a finite set of relevant interactions that appear to occur as a result of something other than observer decisions. A formal analysis of these relevant interactions entails two steps: (i) a pre-analytical decision about what, out of many alternative and legitimate perceptions, should be considered as *the* relevant perceived system to observe in a formal way; (ii) an analytical decision about how to formalize the representation of the selected perception using a finite set of observable qualities. This analytic decision would pertain when choosing a finite set of proxy variables. Therefore, even when it comes to quantitative modeling, the pre-analytical choice of a narrative will determine the quality and the usefulness of the problem structuring used later on for developing modeling schemes and quantification. The choices associated with these two steps arise at the outset of the investigation.

The above ideas boil down to defining the narrative to which the set of observations will belong. By a narrative we mean two things. First we mean the pre-analytical choice of an identity for the observed system in terms of a finite set of relevant attributes and the proxy variables used in quantification. Second we mean the pre-analytical choice of hypothesized causal relations among events supposed to exist within the perception of events in question. Then, the chosen narrative must be relevant for a story-teller (an observer/agent) in the sense that the chosen models and their results must be useful for guiding proper action. By a story-teller we mean an entity/a process that is able to give a kind of legitimacy to the beliefs and goals used when going through the required chain of choices.

When modelers define ''what is'' the modeled system and ''what it does'' in terms of proxy variables, they are adopting an image of relevant interactions, which is then used to generate a representation of a perceived causal relation. In a sense, all representations are simplifications of an infinitely rich set of dynamics, which have been frozen in the given perception of a relationship between a finite set of structures. That is, this image reflects the pre-analytical choices of how to simplify the complexity of external interactions in sense experience. Box (1979) reminds us that, ''all models are wrong, but some are useful''. Their usefulness depends on the quality and the coherence of the choices made in both the pre-analytical and analytical steps of the investigation. Some of this can be taken for granted in physical systems that are confidently represented. But when science deals with the issue of governance, scientific models always require two quality checks about: (i) the relevance of the selected narrative about system's causality; and – within the chosen narrative – (ii) the pertinence and efficacy of the selected formalization in relation to the purpose of the model. That is, a quality check has to verify whether or not:

(1) The selected narrative is relevant in relation to the beliefs and goals existing within a given knowledge system. This point is related to the *semantic* issue, namely, why/what questions.
(2) The selected formalization (or a representation) of the narrative is scientifically accepted in view of codified knowledge in science. This point is related to the *syntactic* issue, namely, how/what questions.
(3) The selected narrative is compatible with the selected formalization in the sense that models and results are effective in the specific context to guide proper action. This last point is related to a *pragmatic* issue, namely, the ultimate test in relation to usefulness for action.

There are thus several facets to the act of freezing a process – using a given perception – into a representation. Handling these three checks is not a straightforward issue, even though it appears tidy in retrospect when the representation is finished.

This examination process was described by Pattee (1995) as a process providing *semiotic closure* with reference to the semiotic process proposed by Peirce (1935). Peirce envisioned the process of formation of knowledge as an endless loop of iteration based on the three following steps with their respective verbs in parentheses: → *semantic* (*transduce*) → *syntax* (*represent*) → *pragmatic* (*apply*) →. The meaningful whole is preceded by a syntactical representation, and it is applied in practical terms to make a realization or an anticipatory model useful for guiding action. This closed sequence offers the basis of the evolution and preservation of beliefs in the path around the cycle.

Various story-tellers, observers and agents are carriers of different beliefs, goals and useful narratives about their own relevant realities. Since life is the interaction of different observers, agents and story-tellers (Rosen, 1985, 2000), it is unavoidable that there will be multiple useful formal representations of their interactions, which can be used to develop effective anticipatory models. Depending on the characteristics and interests of these different observers, agents and story-tellers, non-equivalent representations of different relevant realities will refer to different scales and descriptive domains.

2. The crucial role of the observer/story-teller in quantitative analysis

2.1. *The epistemological implications of hierarchy theory*

All natural systems of interest for sustainability, from complex biogeochemical cycles through ecological systems, to human systems are "dissipative systems" (Glansdorf and Prigogine, 1971; Nicolis and Prigogine, 1977; Prigogine and Stengers, 1981). All dissipative systems are self-organizing, open systems, away from thermodynamic equilibrium. More to the point, they are necessarily "becoming systems" (Prigogine, 1978). As such they invoke a certain complexity, because they operate in parallel, expressing structures and functions on several hierarchical levels. Moreover, these becoming systems change their identity in time. The very concept of self-organization in dissipative systems is linked to the idea of *parallel levels of organization* on different space-time scales. These parallel levels require the observer to use different identities for the observed structures when perceiving and representing them at different scales. Self-organized dissipative systems also involve *evolution*, which implies that the identity of the state space needed to describe the behavior of the observed system in a useful way, changes over time.

The notion of multiple-identities is central to hierarchical thinking. Several writers have suggested that the very definition of hierarchical systems invokes the use of multiple-identities:

- "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).
- "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" in Simon's terminology.
- "a system is hierarchical when alternative methods of description exist for the same system" (Whyte et al., 1969).

We claim that an epistemological analysis of the implication of hierarchy theory has to start with the juxtaposition of a semiotic universe and a physical universe. This relative positioning of the semiotic and the material is done by either observers, or other agents as they become party to dealing with other dissipative hierarchical systems. Different observers/agents perceive and represent situations in a non-equivalent way as they build anticipatory models for guiding their own action or predicting the outcome for observed hierarchical systems. This non-equivalence of observers influences the diversity of plans for action found among the parties involved. The cliché here is the blind men touching the elephant, whereupon they experience different aspects of the same material system. Several non-equivalent observers/agents, for instance a tick, a mouse, a virus, a human being, will use each its own different definition of identity for a dog for purposes of perception and representation. This is turn gives each observer a different set of relevant attributes and expected relations among attributes to be associated with the identity of the dog. We can recall here the definition of *Hierarchy Theory* given by Ahl and Allen (1996):

- "a theory of the observer's role in any formal study of complex systems" (p. 29).

The focus, in this definition, on the role of the observer is to point out the systematic neglect of the relevance of the characteristics of the observer in the standard, disciplinary scientific literature. The role of the observer is at least implied by the other definitions cited above, but we feel the need to address systematically the issue of the observer, only lightly touched in the conventional analysis of hierarchy theory.

2.2. *The relation between scale and identity (multiple scales and multiple-identities)*

Let us start from the scale issue, which is central to the epistemological challenge offered by living systems. There comes a point where a change in scale is not just mean more or less, but leads to something different. Hegel referred to changes in quantity leading to changes in quality, and that is what we mean here. Changes in quality may be either structural or functional changes. Structures and functions must in the end be decided by the observer, and that introduces a semiotic component to the scale issue. There is a semiotic ambiguity associated with the issue of scale. The point we want to make is that contrary to common parlance "*scale*" is only tangentially related to "*size*" of a system or a process. Rather it has to do with the established relation between the perception and the representation of a given instance of a type associated with an identity. This distinction is not easy to grasp, so we will return to it after discussing some examples given in Fig. 1. These examples point at the critical role that the concept of identity plays in the definition of scale.

When looking at the entry "scale" in a dictionary one finds generic definitions such as:

- relative size or extent (Oxford English Dictionary);
- a distinctive relative size or extent (Merriam-Webster).

These definitions sidestep the question: "size relative to what"?

A more technical definition of scale is given by O'Neill et al. (1989):

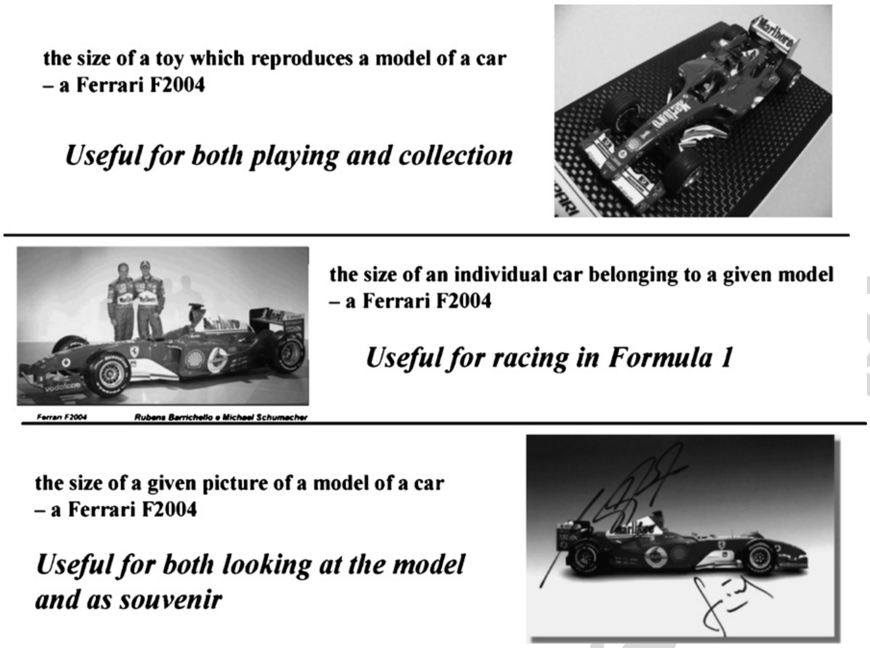

Fig. 1 – The ambiguity associated with the concept of scale.

- a way to describe the physical dimension *of objects of interest* in time and space.

This definition is more satisfactory in that it points more explicitly to ''size'' being associated with *an object of interest* in time and space. The object being of interest is not intrinsic to the thing in and of itself, but rather invokes a pre-analytical *definition*. The issue of scale must consider first the pre-analytical choice of an identity for the object (or system or process) to be perceived and represented. This pre-analytical choice is not a substantive one. Thus, the definition of scale has to do with a pre-analytical choice of an identity used to perceive and represent a relevant aspect of the external world for a given story-teller. Such a choice depends on the characteristics of the story-teller and the context in which narrative is told. The concept of identity is considered here as a semiotic tool which is selected, in a pre-analytical step, to perceive and represent ''what is'' the system under analysis in a useful way and ''what it does'' within the chosen representation.

Once the concept of identity has been introduced, then we can say that scale has to do with the ''size'' of something. But the issue is still not simple. Both living systems and systems fabricated according to an external design are realizations of some essence that lies behind the things we see in the world. The size mentioned above is of a realization associated with *a given identity*.

To clarify this statement, consider Fig. 1. The figure shows three representations of the same ''system'' (or ''object of interest''), with which the concept of scale can be associated:

(1) The size of a toy which reproduces a model of a car—a Ferrari F2005. The toy is a relevant entity for collection or for playing.
(2) The size of an individual car belonging to a given model of race cars—a Ferrari F2005. This car is a relevant entity for racing in F1.
(3) The size of a given picture of a model of a car—a Ferrari F2005. This picture is a relevant entity for representing the characteristics of a Ferrari F2005 or as souvenir.

In these three examples of entities associated with the ''*scale*'' of ''a Ferrari F2005'' we deal with different sizes of individual realizations of the type of interest: the size of either the toy or the race car or the realization of a representation of them—the picture. The first two realizations map onto the same template, the expected relations of parts and whole associated with the name of the type ''Ferrari F2005''. Different is the case of the picture of the car. There is ambiguity as to whether that picture is of the race car or the toy, and more to the point, it does not matter. At this point, the representation in the picture maps ambiguously, but only at one level of analysis—when considering realizations. At another level there is only a single source, the set of expected relationships associated with the name ''Ferrari F2005''. With that insight it becomes clear that both the toy and the race car are simply realizations of the same set of relationships set in a structural type associated with their organized structure. The race car only gains privilege if actually racing a car is the issue. But this requires considering the functional type and not the structural type. If it is a matter of playing, the toy gains the ascendancy instead. Any special racing car associated with the name is not in particular ''the real thing'', it is just a realization, in the same manner as any special toy is just a realization. The ambiguity as to which realization is represented in the picture makes the point that both the race car and the toy are just realizations. In a sense, the only stable, unambiguous reality is *the meaning* associated with the name ''Ferrari F2005''—either in terms of an expected structural or an expected functional type. After having decided to deal only with the definition of structural type, it becomes possible to calculate a relation between the two relative sizes, that of a given representation (e.g. the size of ‘‘the picture reproducing the car’’) and that of the original system which is mapped onto the representation (e.g. ‘‘the realization of a real car of this model which has been photographed for making the picture’’). Then, the ratio of sizes determined in the analogous topological correspondence over the resulting perception of the ‘‘the original’’ and ‘‘its representation’’ is the classic definition of scale adopted in geography for geographic maps.

In Fig. 1 we have three distinct elements in play:

(1) *The mental image associated with the name ‘‘Ferrari F2005’’* (e.g. an expected topological relation among subparts and parts, parts and the whole) which makes it possible to recognize a realization of it when we see it. This is a mental structural type associated with the name, which does not have scale. The fact that *types do not have scale* (Allen and Hoekstra, 1992) is crucial, since this is what makes it possible to make models. Since both *the toy* and *the real car* map onto the same type, they are models of each other—they share the same template which is realized at different sizes (Rosen, 1991).
(2) *Physical realizations of the type named ‘‘Ferrari F2005’’*. These individual realizations can belong to different equivalence classes. The class of the real racing cars all map onto the same template, but their size will depend on the characteristics of the process of fabrication. All the members of the equivalence class ‘‘racing car—Ferrari F2005’’ are made using the same process of fabrication and the same blue-print. The same applies to the class of toys, which map onto the same template and have a size which depends on the characteristics of the process of fabrication. It should be noted, however, that even though each one of these realizations belongs to a given class (either toys or racing cars), each realization is special. Individual instances do have a unique history and special characteristics which can be detected only when analyzed at a certain level of detail and accuracy that lies inside the error bars used to describe the characteristics of the class.
(3) *Representations of a realization of the type named ‘‘Ferrari F2005’’*. This is a physical entity (the picture on the page of this Journal or the image on a screen for those reading this paper in an electronic version) representing an original realization.

There is an unavoidable ambiguity in our local perception, between realization and representation. For example a cursory reflection over the relative size of the three images shown in Fig. 1 will convince the reader that it is not possible to define, in substantive terms, WHAT or WHICH ONE has the largest size in that figure. In fact, in Fig. 1 we have: (A) two representations of two material realizations (the same model of car realized at different sizes—toy and racing car) and (B) one representation of a representation (the image of the picture with autographs on it). In order to establish a ranking of size we should first specify whether we are talking about the size of the original realizations which are represented or the actual size of the representations.

3. The concept of identity as a semiotic tool for sharing experience

3.1. *The concept of identity*

The etymology of the term *identity* comes from Latin *identidem*, which is a contraction of *idem and idem*, literally ‘‘*same and same*’’. Therefore, the very concept of identity has to do with a mapping: ‘‘*the observed*’’ must map onto something used as an expected ‘‘*reference type*’’. It helps to break that process down into steps. An identity implies using a given name (label) which must be associated with two tasks performed simultaneously:

1. To identify mental images useful for recognizing objects of interest. Those images consist of expected relationships between attributes of types used to represent the organizational structure of members that belong to an equivalence class.
2. To identify physical entities perceived as legitimate members of that equivalence class. Individual realizations of the relative equivalence class must express the expected patterns so as to be recognizable when the mental image is used in a comparison.

Three elements are needed to generate a working identity. They are required by an observer in order to establish an ‘‘idem’’ and ‘‘idem’’ relation between what is observed and the epistemic tool used for recognize and characterize it. First, is the meaning of the name of the identity. Second, is what is expected by a standard observer, in a general setting, when dealing with a particular identity. Third, is what is observed specifically by a local observer, when dealing with an element which is associated with a given identity. Let us work though the implications of these three elements.

- *The first element*. The meaning of the name of the identity. An example here might be the meaning for an English speaking person by the word DOG. Obviously, *DOG* is the name of ‘‘that’’ identity in English, but that same identity gets different names in different languages (*Perro* in Spanish; *Chien* in French; *Inu* in Japanese; or *Cane* in Italian). That is, the ‘‘name’’ of an identity can have various names. There needs to be a distinction here between: (a) semiotic mapping that makes it possible to have different names for the same meaning; and (b) formal mapping in which the name of the name is univocally represented by a given label. In the first distinction a semiotic meaning has a many to one mapping. In the second distinction a formal mapping operates as a one-to-one mapping.

  Cooke (2001) makes the distinction between functional language and procedural language in software design, and that contrast applies to the distinctions above. Functional language is based on ‘‘context dependent’’ semiotic instructions (‘‘do the previous operation on the remaining items until none are left’’). This implies that several operations can be mapped by the identifier ‘‘previous operation’’ depending on the context in which the instruction is used. The same applies to the identifier ‘‘remaining items’’. Meanwhile a procedural language is based on interconnected data structures (the set of data that will used named one by one using labels—$X, Y, \ldots, Z$), and a list of instructions that modify them ("sum X to Y and then multiply by Z").

This distinction between processes which are based on semiotic phenomena as opposed to processes based on mechanical phenomena is crucial. The concept of identity belongs to a universe of discourse in which the existence of semiotic activity must be explicitly acknowledged. That is the first element of an identity is not about the particular formalization given to the name (*dog* versus *perro*). Rather it is about the possibility of assigning a shared meaning to a given label, which can be stochastically chosen as the name of that identity. Put another way, an identity requires a situation in which "something" relevant for "someone" needs to be named. This implies that in order to have an identity it should be possible to learn at the outset how to share the meaning of a sign or a symbol.

- *The second element* – what is expected by the standard observer – at a LARGE SCALE. The name dog is associated in the mind of the observer with a set of known relations over attributes (face, shape, standard association of parts into a whole) expected for the observer type. These mental images associated with the name "dog" are shared by the population of users of a language. These images can refer to the shape and parts of dog skeleton, to the internal organs and their reciprocal location, the face pattern, the shape of the Fox Terrier, the four varieties of Belgian Shepard, the characteristics of Cocker Spaniel. Moreover, in identifying a biological system, there is bonus information. Biological identities are organized in nested hierarchies. With the identity of a "dog", an observer can safely assume the characteristics associated with the identity of a "mammal" (e.g. a fur, two eyes, two hears, warm blood, two sexes) or "vertebrate" (e.g. a vertebral column, post anal tail).
- *The third element* – what is experienced by a given observer – at a LOCAL SCALE. When interacting with individual realizations of the equivalence class "dog", an observer looks for the right set of patterns in the incoming signals. The observed patterns have to match the expected patterns associated with the mental images that come when thinking of dogs. That is, individual organisms belonging to the species *Canis familiaris* should result in legitimate members of the same equivalence class, all mapping onto the same type/template. When members of a class map onto the same template, then it becomes possible to use what has been learned at the large scale to predict characteristics and possible behavior of the individual realization with which there is a local interaction. This implies a transfer of information across scales. Knowledge developed at the large scale by a culture, using a given language, about the expected characteristics and behaviors of the equivalence class of dogs can be applied, at the local scale, by an individual person, to handle the interaction of a given individual realization of dog at a point in space and time. The validity and usefulness of the identity DOG entails/requires the existence of an equivalence class of organized structures – dog organisms – sharing a common template. In fact, it is necessary to have an equivalence class of organized structure in order to be able to describe and recognize individual members of it using a common type. In turn the existence of an equivalence class entails/requires the ability to establishing a reliable process of fabrication of members of the class. This fabrication should be capable of generating a consistent supply of realizations of the given type (DOG) using the same template. In biological systems this is possible through DNA, which can preserve and replicate the blue-print for new organisms of a given species.

The discussion on the concept of identity can be wrapped up using Fig. 2:

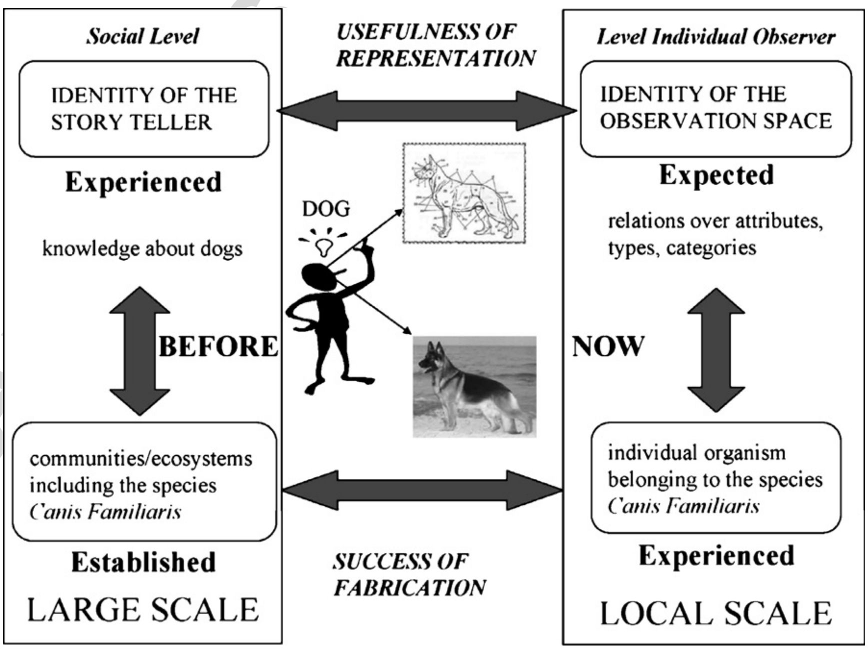

Fig. 2 – The relations across scales entailed by a semiotic identity.

- *On the semiotic side of the observation process*. For population of different observers to share the meaning of a label used for an identity (*dog* in English, *perro* in Spanish) the characteristics of the system associated with the given identity (e.g. dogs) must have been experienced in a large space and time domain. That domain must be much larger than the one at which individual observers are making their own observations. When a new observer is born into a society the knowledge about the identity "dog" is already present. Individuals can only integrate their own personal experiences about dogs within the pre-existing experience of dogs learned before by the culture of the society in which the individual has been educated.
- *On the ontological side of the observation process*. The various realizations belonging to the equivalence class identified with the identity "dog" must generate the same expected images associated with that name. This expectation has to be confirmed in the different signals gathered by different observers looking at dogs using a similar observation protocol. In order that there should be an effective external referent of a given identity, an equivalence class of organized structures must be established at a scale much larger than the one at which local experience occurs.

Learning how to develop and use anticipatory systems is typical of life (Rosen, 1985, 2000). This anticipation is associated with the ability to express semiotic activity: "there exist entities in the world (like 'meaning' of signs) which can influence *only living systems and not non-living ones*. Semiotic phenomena do not belong to physical reality" (emphasis added, Kull, 1998). The field of bio-semiotics implies breaking a taboo associated with a key assumption of conventional reductionism. In the universe of semiotic phenomena it is possible to have entities which organize our experience, even though they are not tangible. A name is the result of a semiotic process which assumes experiencing now, at the local scale, what has been established in the past, at a large scale. Making sense across processes occurring at different scales translates into the existence of an "essence" in the semiotic universe, which does not map onto anything tangible in the physical universe.

3.2. A semiotic identity can generate bifurcations in legitimate formalization when different narratives and different perceptions are assigned to the same label

Mandelbrot (1967) makes 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. The more detailed the map, the longer will be the length of the same segment of coast. In the case of geographic objects, we deal with special realizations of types expressing multiple lengths of coast, depending on the scale of the measuring device. Here we will give "the length of the same segment of coast" an identity. But the identity here is not a simple matter, because it is possible to assign to the same semiotic identity (the meaning associated with the label "the length of the coastline") to different formal identities (different measurements of realizations of representations). As a result it is not possible to get a formal representation here without first specifying the scale at which we will perceive the situation to be represented (for more Giampietro, 2003, p. 65). Narrative enters the discussion, because without reference to a narrative, choice between scales is arbitrary. Nonetheless, in this example, choice of scale also constitutes choice of a descriptive domain, which is required in order to have a formal representation. Under these conditions, arbitrariness carries important implications. It requires checking the

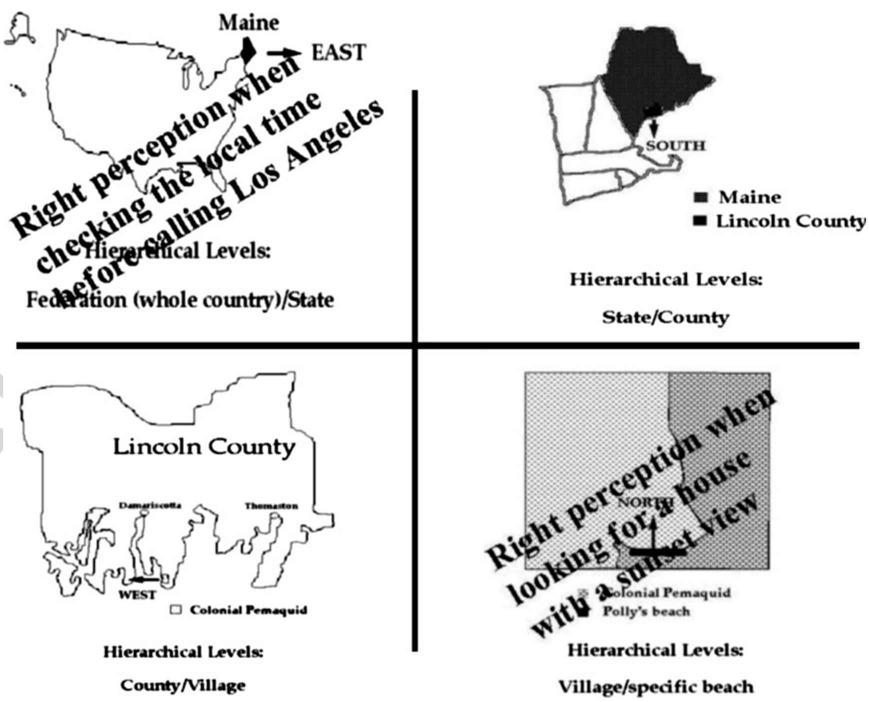

Fig. 3 – Non-equivalent perceptions of the orientation of the coastal line of Maine at different scales.

usefulness of the narrative within which the formalization is taking place.

Building on the insight provided by Mandelbrot we can say that the same piece of coastline can be perceived and represented as oriented toward the East, South West or North, – see Fig. 3 (after Giampietro, 1994) – depending on the context. In this example, the epistemological ambiguity is associated with the interpretation of the label ''geographic orientation of the coast''. At the level of the country or continent, Maine is on the East Coast of the United States. However at the level of county or state, the coast of Maine, as a state, faces toward the South. At a lower level of the town in a county, the some parts of the coast of Maine face the West. At a yet lower level, an individual beach may face to the North—e.g. Polly Beach in the town Pemaquid is oriented toward North. In all these cases rigorous experiments can be conducted to prove the truth of each orientation. In this example, the ambiguity is generated by the fact that Maine is an entity which can be perceived and represented at different scales.

When defining Maine as being on the East coast of the USA we are adopting as external referent for assigning meaning to the expression ''geographic orientation of the coast'' the relative position of continents on the globe. In this narrative, continents are the relevant parts of the whole, and their relative position is defined over a sphere. Meanwhile, when defining Polly Beach as oriented toward the North, we are adopting as external referents the direction indicated by a compass, when standing on the beach. Such an orientation of the local beach comes from a representation of the area as related to a flat map. Within such a narrative the lines going to the North Pole are formalized as parallel. So the two non-equivalent narratives about the relative position of objects assert that the same expression ''orientation of a tract of coast'' may have different meanings in different contexts. By using different contexts for the investigation, a given assertion as to the orientation of the piece of coast may be scientifically falsifiable, while it can also be shown to be true. We labor this example to show that empirical validation, *per se*, is not enough to guarantee a pertinent and useful analysis. If we want to make a phone call to Los Angeles from Maine and we want to calculate the difference in time zone, then it is the narrative of the relative position of continents – the East coast with meridians converging at the North pole – that provides the useful analysis. Whereas, if we want to buy a house with the porch facing the sunset, then for pertinent analysis we need the narrative of Polly Beach facing North on a flat map where the meridians will never converge.

4. The special organization of living systems and the elusive identity of holons

4.1. *The special organization of living system*

The metaphor of the *holon* discussed in this section is based on the peculiar characteristic of the organization of metabolic systems. As suggested by the seminal work of Prigogine's school (Prigogine, 1978; Prigogine and Stengers, 1981), human societies and ecosystems both belong to the class of dissipative systems. These systems are able to maintain their own identity because of a continuous process of metabolism, which requires the ability to stabilize a coordinated inflow of matter and energy resources. Meanwhile, metabolic systems also dispose of the flow of degraded matter and energy flows into their context. Living and social systems have an additional peculiar characteristic. They can generate a predictable pattern of dissipation of their inputs, such as food, fossil energy and useful materials for human societies (solar radiation, nutrients and water for terrestrial ecosystems). Critically, living and social systems use their metabolic inputs to express semiotic activity. In this way, living systems are capable of learning how to improve interaction with their environment while actively creating themselves. This creativity includes reproduction of existing structural and functional patterns while gathering of data and running anticipatory models about themselves interacting with their context (Maturana and Varela, 1980; Rosen, 1985, 2000; Pattee, 1995). In this way they are learning and adapting over time by updating their anticipatory models of their own interaction with their expected context. That is, living and social systems are capable of continuously updating their own identity.

Finally, the metabolism of complex adaptive systems such as ecosystems and human societies is based on a network of energy forms controlling each other. The control is via a series of positive and negative feed-backs able to modulate the occurrence of autocatalytic loops (Odum, 1983; Ulanowicz, 1986, 1997). The various elements making up these networks must express characteristics that can be expected. Expectations are met by the elements being associated with their respective encoded identity. In real time, syntactic aspects of the system are used in the pragmatic phase of construction and reproduction of realizations, setting up the elements of the network to play their roles. The syntax and pragmatics are those we mentioned earlier in the parlance of Peirce (1935). For example, the metabolism of a cow, a liver of a human being, a car, or a city in a developed country, can be studied in terms of expected patterns that have a basis either in coded genetics, blue-prints or established regulations. The different elements of these networks, operate on different scales, expressing their typology of metabolism on different scales—e.g. cells making up organs, organs, individual human beings, households, villages and whole countries. The co-existence of different relevant scales requires the elements of these networks to be perceived and represented in non-equivalent ways (Giampietro, 2003).

Organization in complex biological and social systems may be maintained in a hierarchical conception of the whole. The hierarchy notes strong constraint on the compatibility of the characteristics of the various elements performing different roles at different hierarchical levels, within the same organic whole (Ulanowicz, 1986; Pattee, 1995, 2000; Giampietro, 2003). To simplify such a technical discussion we illustrate in Fig. 4 a key concept associated with the peculiar nature of dissipative network. Metabolic systems operating across multiple levels and scales must be able to establish a forced correspondence between a functional type and a structural type. When dealing with ''*an element*'' of a network interacting with ''*the rest of the network*'' we can define the characteristics of that element in two non-equivalent ways. We can unpack these ideas with the example of Fig. 4: the heart of a human, is the *element*, fitting

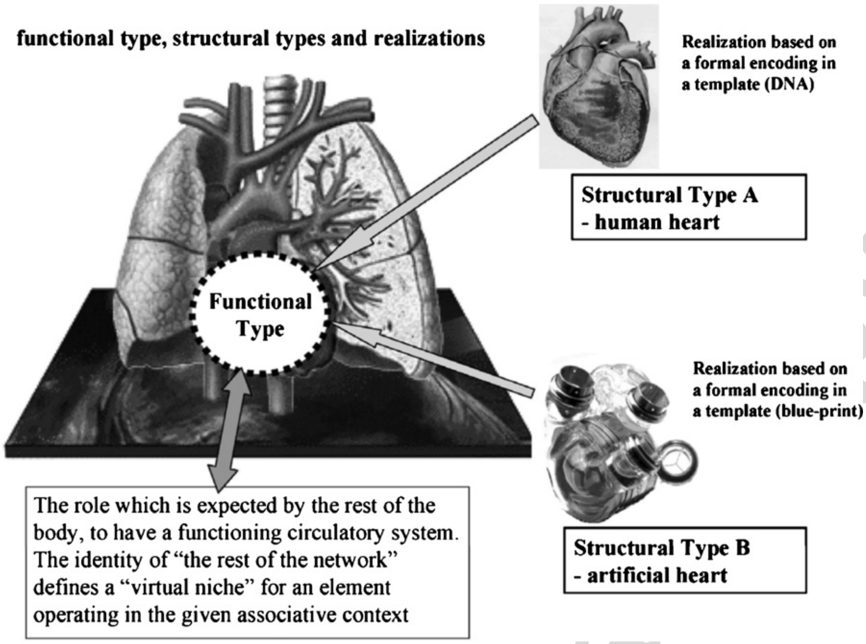

Fig. 4 – The characteristics nature of organization in living systems.

into the *rest of the network*, a functioning circulatory system operating in the rest of the body. We see that more than one definition is required for this element. From hierarchy theory, we can say that the different definitions depend on the level of analysis and conception. Functional meaning comes from looking outward and above; structural meaning comes from the level of the structure itself; while mechanical functioning of how the heart works coming from the level below.

Definition #1 – from outside the black-box – the functional type of a heart. It represents the behavior expected ''from that element'' by the rest of the network to which the element belongs. That is, there is an image of the heart, associated with the mutual information carried out by the various elements making up the network. The mutual information refers to the interface between two hierarchical levels (the *level* n = the whole heart; and *level* $n+1$ = the network of the rest of the body to which the heart belongs as a part). This is the functional type determining the functional characteristics defining a performance expected by the rest of the body in the pulsing of the heart. The definition of a functional type defines an equivalence class of structural types of pulsing heart, which can be transplanted into the given body with the goal of keeping it alive. Both a natural and an artificial heart meet this definition. In the example of Fig. 4 there is a functional type – *e.g. pulsing heart* – which can be associated with the ability to perform the expected function. The essence of this functional type defines the *role*, a semiotic identity or meaning, assigned to the organized structure used for the job. Such a role is defined, in semiotic terms, as the ability to express an expected behavior of a given object. Therefore, a role is an expected behavior which must be beneficial when considered on the interface the whole – the heart – to its associative context—the rest of the body. The notion of associative context comes from Rosen (1991) and brings in the idea of an essence for biological and social structures. An essence is the role played by a structural type within the given associative context. This expected behavior obviously must be expressed by an equivalence class of structural types which must be capable of doing the required job. Therefore, the definition of an essence/functional type is associated with the *why question*. An essence justifies why a functional type is relevant for the associative context and therefore why we bother learning about the relative perception and representation. In this way, an essence defines what is relevant for the story-teller in an equivalence class of structural types, which should be considered when answering the *how question*. A functional type defines an equivalence class of structural types: the class of all those structural types able to perform the expected function (in this example either an actual human hearts or a heart–lung bypass machine).

Definition #2 – from inside the black-box – the structural type. It represents an organized structure which has to be generated through a physical process of fabrication, which maps onto a given template. Such a structural type refers to the interface between two hierarchical levels (*level* n = the whole heart; and *level* $n-1$ = the components of the heart, which are assembled in a particular way to generate the whole). In the example of Fig. 4, there are two structural types – *artificial heart versus natural heart* – which both belong to the same equivalence class of ''pulsing heart'', in relation to the essence/functional type. They can both be used to keep alive a person by pumping the blood in the circulatory system. In turn, each of these two structural types defines the characteristics of the two relative equivalence classes of realizations. That is, there is an equivalence class of all the realizations of artificial hearts, which is distinct from the equivalence class of all the realizations of natural hearts. In fact, these two classes are based on different typologies of structural organization. A structural type is defined by a *template* that can be formalized in a blue-print, associated with a fabrication process. The use of the same template in the process of fabrication is required for guaranteeing a common pattern of structural organization to the various instances of the same class. The expected behavior of a structural type refers to the interactions occurring on the interface ''parts of the heart'' (*level* $n-1$)/ ''whole heart'' (*level n*). Therefore, the definition of a structural type is associated with the *how question*. It assumes that the function of a heart is relevant and useful ''by default''. That is, a discussion over structural types makes sense only after having accepted the validity of the functional types to which they refer. A structural type explains and defines only the organization required to guarantee the feasibility of the equivalence class of realizations. These realizations must be able to perform the given function associated with the relevant essence (when operating in the right associative context).

In the example of Fig. 4 we can see an additional epistemological complication, in that both definitions can be associated with *a realization/instance of a structural/functional type* (*not belonging to the representation*). A realization/instance of the structural type would be represented by any particular entity which is pumping blood for real. It could be any given realization of either a natural or an artificial heart which is plugged into the functioning circulatory system of a given individual human being. This organized structure is obtained by following a process of fabrication based on a given blueprint which maps onto the relative template. This ambiguous mapping of the same physical realization to either a functional and/or a structural type is at the root of the epistemological ambiguity embedded in hierarchy theory.

The example of the heart can be interpreted in an alternative to hierarchy theory using network theory (for more details see Giampietro, 2003, based on Rosen, 1958). Consider a given network in which: (i) the graph of the connection among the nodes is known and stable; and (ii) the identity of the various elements operating at the different nodes is kept constant through a process of reproduction and repair. It becomes possible to define the expected identity of the element of a given node in two non-equivalent ways: (i) by using the mutual information carried out by the rest of the network; (ii) by studying the structural organization of the realization operating at the node. The above is a set of assumptions. When they are valid in considering a network, the combined information stored in the identities of the elements of the other nodes (at the *level n*) and by the graph of connections (at the *level* $n+1$) defines a ''network niche'' – the essence – for an element supposed to occupy the given node. In this situation, whatever instance of structural type would be used to fill the given position in that network, it will have to be able to process a certain set of inputs and deliver a certain set of outputs at the speed, as is expected by the rest of the network. That is, any structural type used to make realizations of an element of the node must fit the functional type associated with the essence of that node. 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 by considering simultaneously different types of information stored at different levels.

To conclude we can say that when considering the semiotic side (the *why* for the story-teller) the definition of an essence is associated with the relevance of the relative semiotic identity. For a story-teller an essence is the definition of *an equivalence class of functional/useful types*. The definition of an essence is very simple for a narrator: if it works in relation to a relevant goal, then it is real in the semiotic world of the narrative. Such a judgment is independent of the tangibility of the relative realization. We can still remain agnostic as to whether or not ''real'' here pertains to an existence in the singular external world, so we are not necessarily taking a realist philosophical posture. When considering the ontological side (the *how* for the fabrication process) the definition of an essence must be associated with feasibility of the external referent baking up the relative identity. An adequate physical reality must be in place to make possible the exchange of signals to be interpreted in the semiotic process. Because of this, when modeling a given perception of real world problems, where physical phenomena are the objects of analytical interest, the universe of semiotic phenomena must always be coupled relative to a universe of physical phenomena. Any definition of a set of functional/useful types (essences) is always ''constrained by'' and ''dependent on'' the existence of a compatible set of *equivalence classes of structural/feasible structural types* operating at different scales. This discussion of essences leads us to the concept of holons.

4.2. *The elusive identity of holons*

Complex organization of living systems deeply mixes physical and semiotic activity. Simon (1962) casts this issue in terms of ''organized structure'' and ''relational function''. Bailey (1990) proposes the same approach for social systems using the terms ''incumbent'' and ''role''. Salthe (1985) suggests a similar combination of descriptions based on yet another juxtaposition of terms: ''individuals'' and ''types''. Finally, Rosen (2000) proposes, within a more general theory of modeling relation, a more drastic distinction which gets back to the Greek philosophical tradition. He makes a distinction between: ''individual realizations'' and ''essences''. Realizations are always ''special''. They cannot be fully described by any scientific representation, because any individual maps only imperfectly onto its relative type. That imperfection comes from the unique history of the realization. The essence is associated with the semiotic characteristics of an equivalence class of functional types. The parallels between the various couplets of terms are quite evident.

There is a common semantic message found across the full set of couplets. It calls for a simultaneous use of two complementary views for defining the elements that make up ecological or social systems. To this regard, Koestler (1968, 1969, 1978) proposed the metaphor of the holon. The holon has the double nature of ''whole'' and ''part'' of components of ecological or human systems. These part/whole dualities 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). The term holon may be associated with the duality typical of the Eastern concept of *Yin-Yang*. Holons must simultaneously fit two typologies of WHAT/WHY and WHAT/HOW. What/why entails the large scale view that defines a relevant functional type. What/how addresses the local scale view that defines a pertinent structural type. Koestler's holon is a combination of two Greek words: (1) the word HOLOS means the whole with constraints from the macroscopic view; (2) the suffix ON refers to the part or particle (as in proton or neutron) with its constraints from the microscopic view. Holon as a concept entails two major epistemological problems:

#1 *The scale that is used to perceive and represent "realizations of organized structures" is different from the scale used to perceive and represent "functional relations".*

Consider the example of the Presidency of the United States. In this example the considered holon refers to a natural identity found in a social system, the President. Mr. George W. Bush is the actual "realization of an organized structure" that is now the "incumbent" in the "role" of President of the USA. Different individual human beings can perform such a role for a limited finite time. By contrast, the role of US Presidency, as a social function, is a functional type which has a time horizon estimated in the order of centuries. The perception and representation of individual realizations of the structural type (the various incumbents) and the functional type (the various images and written definitions associated with the institutional role of US presidency) are based on a different selection of relevant attributes. Even so, when we refer to the 'President of the USA' we loosely address such a holon, without making a distinction between the role (social function) and the incumbent performing that role. You cannot have an operational US President without the joint existence of a valid role associated with an effective structural type and a valid incumbent verified in the election process. The role needs institutional settings for its validity. The effective structural type should be someone born in the USA, who is 35 years of age or older, and has been legally resident in the USA for 14 years (according to the US Constitution, Article II §1). A valid incumbent represents a realization of the required structural type. Confusion is exacerbated by the fact that this double coupling

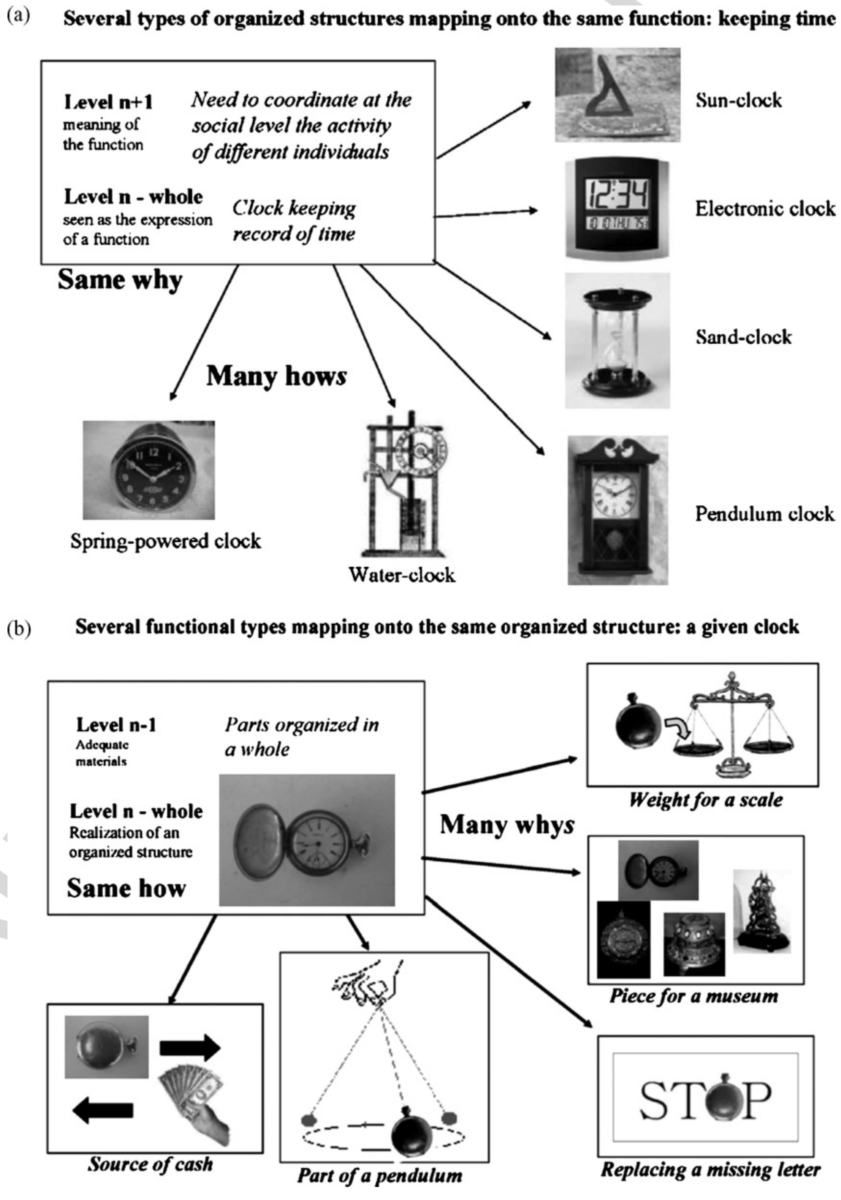

Fig. 5 – Possible coupling of functional and structural types.

is logically independent. The identity of Mr. Bush as a particular realization of the organized structure (e.g. an adult human being) able to perform the specified function of 'US president' is logically independent from the identity of the role of the Presidency of the USA. That is, the images used to represent physiological characteristics of human beings are logically independent from those used to represent the characteristics of social institutions. Human beings were present in America well before the writing of US constitution. In the same way, the American constitution has a life span much larger than any of the incumbents in the role of the US President.

#2 When dealing with holons it is impossible to have a substantive one to one mapping between "types of organized structures" and "types of functional relations". The universe of the possible coupling of structural and functional types is open and expanding.

Two examples of this point are given in Fig. 5a and b, a pair of figures that explore the different facets of a timepiece. The examples given in Fig. 5a illustrate having many different structural types (many HOWs) that map onto the same functional type (the same WHY). In this case, after defining the performance associated with a given role, we can learn how to increase the efficiency of structural types. That is, we can compare the performance of the various HOWs against the given requirement associated with the WHY.

The inverse of this situation arises in the examples given in Fig. 5b. In this case, we have the same HOW associated with an individual realization of a structural type. When this individual realization is moved to a different context, the same organizational structure of this individual can map onto a different WHY. That is, depending on the context, the same structural type can perform many different roles. In the

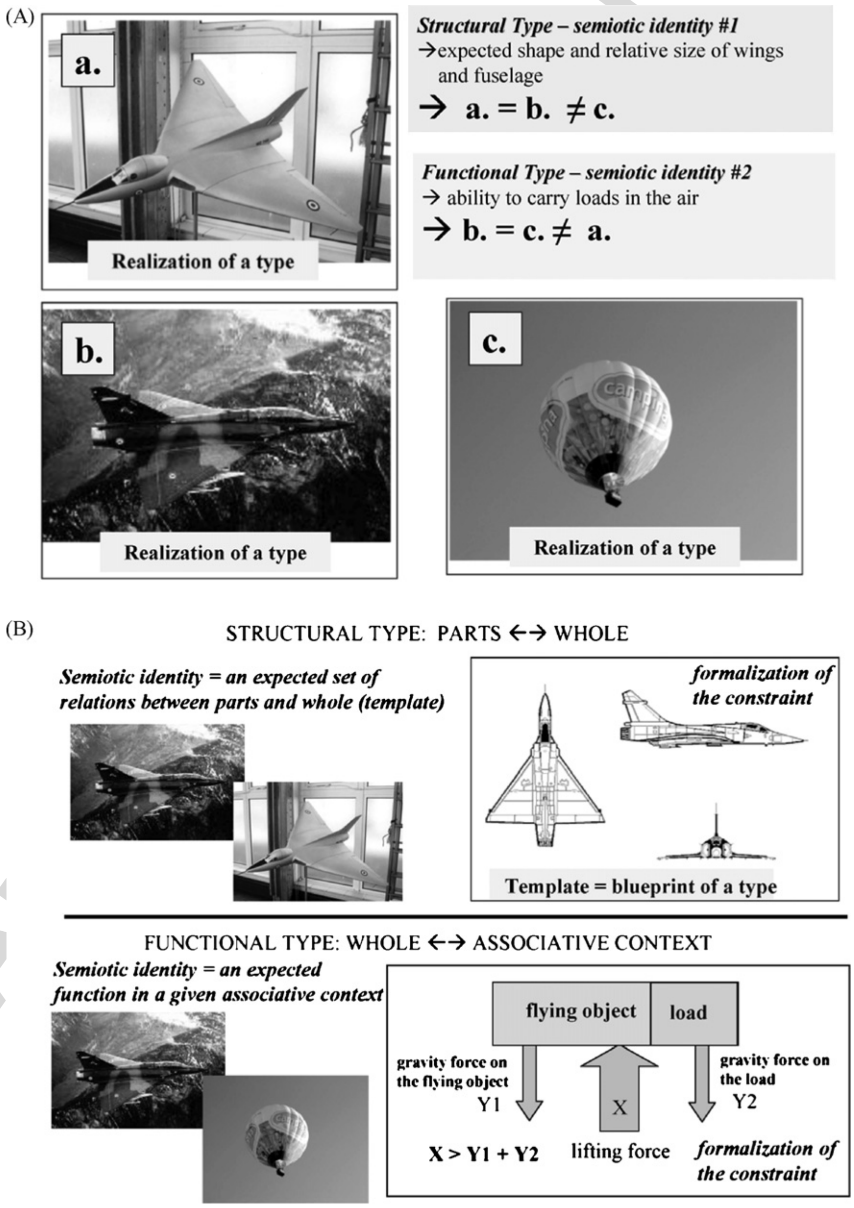

Fig. 6 – Non-equivalent coupling of functional and structural types.

example given in Fig. 5b, the structural type ‘‘old mechanical clock’’ can become the structural type as ‘‘object worth putting in a museum’’. This new functional type is associated with 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. This is an example of emergence, in which a new combination of structural organization, carried out by an individual realization, is coupled to a different associative context (a latent demand for new functions expressed by the system of knowledge in which meanings are created and preserved). In the new context a given realization of the old structural type generates new meaning, and therefore a different function for the organized structure in question.

When dealing with the evolution of Holarchies (a system made up of holons—Koestler, 1969, p. 102), we should expect a continuous loss of a one to one mapping between realization of structural types and functional types:

(1) When we can assume as valid the definition of the functional type for the model, then we can have many structural types mapping onto the same functional type (many *hows* for the same *why* of a clock as in Fig. 5a). In this situation, the different performances of these different structural types can be compared. Here we are in the realm of design and efficiency.
(2) When a sudden change in boundary conditions makes it possible, a given realization of a structural type can perform a function which is different from that for which that original structural type was originally fabricated. In this case, a new useful function can generate press for the introduction of a new natural identity (a new holon), associated with a new definition of role that has to be fulfilled. As illustrated in Fig. 5b, a virtually infinite universe of *whys* can be assigned to the same *how*, depending on the circumstances. This is the realm of emergence. Whenever a new natural identity is expanded to a point where it becomes a recognized essence (a recognized functional role at a large scale) a new functional type is born.
(3) As soon as a new holon is born it becomes possible to define in more formal terms, the relative functional type, that is, to characterize what is the role expected by the structural type. As soon the role can be defined in formal terms, then it becomes possible to look for improved structural types – in terms of efficiency – on the ontological side. Evolution can be seen as a continuous, process in which: (i) the definition of functional type is used to design better organized structures; and (ii) the realizations of better structural types are used to explore new behaviors requiring the use of new natural identities (holons) capable of expanding the set of meanings shared by a knowledge system. When dealing with this process it becomes impossible to maintain over time a valid formalization based on the existing coupling of structural and functional types. This is the realm of ignorance faced by modelers asked to deal with evolution and emergence.

The problem entailed by the simultaneous formalization of both structural and functional types is illustrated in Fig. 6. These two equivalence classes require the use of logically independent definitions of the relative types. Different structural types can perform the same function – airplanes and balloons – whereas the same template may not necessarily be associated with the same function—flying airplanes versus toy airplanes. This implies that, when dealing with a particular holon operating at a given point in space and time, it is always necessary to check in semiotic terms the particular coupling of structural and functional types. What is interesting in this example of different aspects of flying objects is the difference in the formal representation adopted in science for structural and functional types. Templates can be handled using images—in terms of expected topological relations over parts and wholes not changing in time. Functions tend to be handled using equations – in terms of ability to induce expected changes in time over a given state space – a given universe of possible changes.

5. The distinction between models (based on a strong semiotic identity) and similes (based on a weak semiotic identity)

5.1. *Rosen theory of modeling relation*

The material presented in this section is derived from the work of Rosen (1977, 1985, 1991, 2000) and is discussed in more details in Mayumi and Giampietro (2006) and Giampietro et al. (2006).

In developing his theory Rosen introduces the concept of ‘‘natural system’’. In our vocabulary this would represent the semiotic identity assigned to the observed system, which is adopted to perceive and represent relevant changes. According to Rosen, a modeling relation in natural science aims at establishing a protocol whereby expected variations in relevant qualities of a ‘‘natural system’’ are mapped onto changes occurring in a set of encoding variables to which one can assign numerical values through measurement. Therefore, encoding a semiotic identity into a set of proxy variables amounts to assigning a formal identity to that natural system. An overview of this idea is given in Fig. 7a.

The relevant qualities to be considered in the model depend on the perceived identity of the natural system. They must be captured in the model using an appropriate formal identity. To do so, the relevant attributes associated with the semiotic identity of the system have to be encoded into a finite set of proxy variables. This encoding defines an image of the natural system making it into a model. Here the model is the formal identity of the natural system based on the value assumed by the set of proxy variables. Once this relationship to the proxy variables is established, it is possible to simulate the relation of causality perceived in the natural system, by applying a formal system of inference. The mechanism of entailment generated by the mathematical model has to predict the change in observable qualities of the natural system. According to this general scheme proposed by Rosen we can say that a valid model must be able to establish a pair of congruencies. Those links are between: (A) a perceived pattern of causality in the natural system (indicated by the arrow #1). This is the story-teller’s belief about causality expressed within a given narrative; and (B) the pattern generated by the

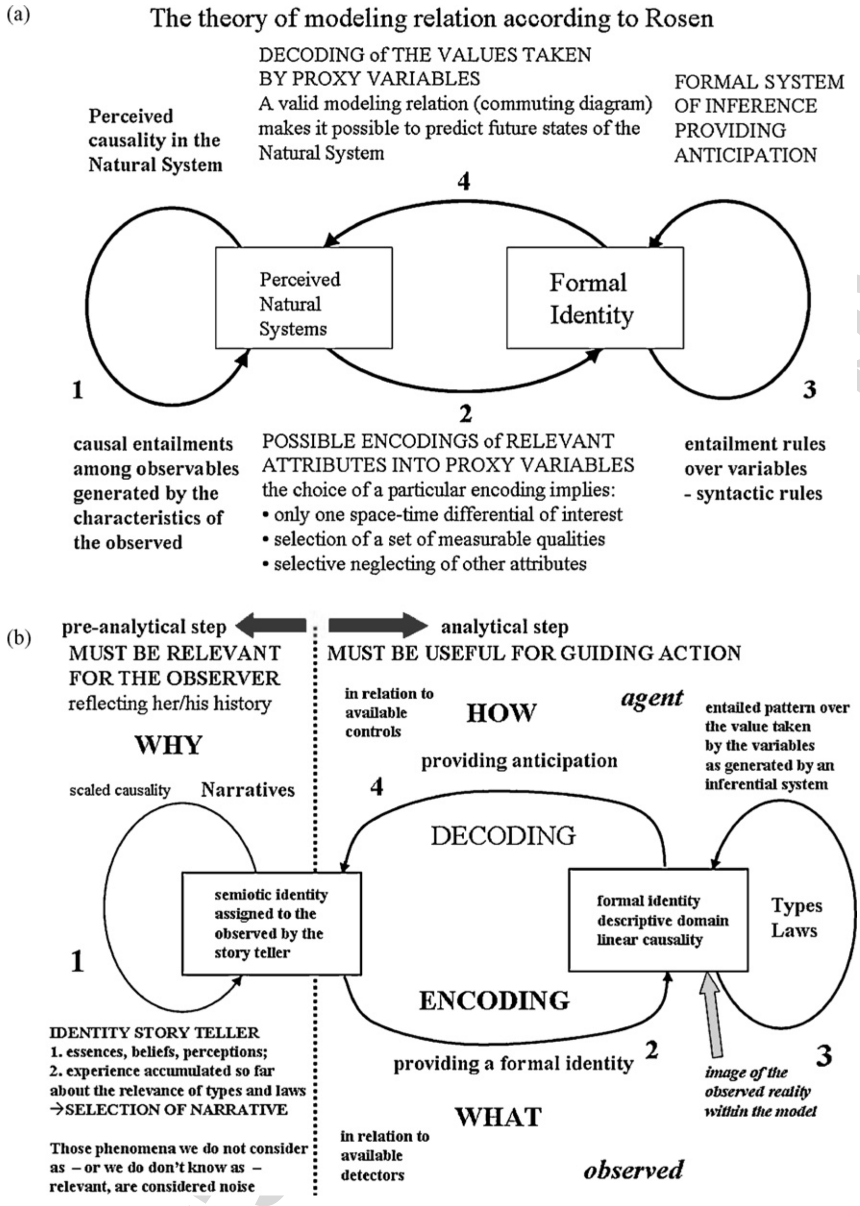

Fig. 7 – Two views of Rosen's modeling relation.

formal system of inference using proxy variables adopted in the model (indicated by the arrow #3).

To obtain this result the modeler has to take two crucial steps: encoding (indicated by the arrow #2) and decoding (indicated by the arrow #4). The encoding step refers to a process in which the set of observable qualities associated with the semantic identity are translated into a formal representation. The semiotic identity includes all the qualities associated with the natural system. In the example of the dog, this would represent, the universe of expected qualities associated with the word "dog". The universe of these qualities is open and expanding. For this reason it is necessary to transform the semiotic identity into a formal identity so that one can represent change in the model. In fact, only a formal identity based on a finite set of observable qualities can be handled in terms of computational capability.

Therefore, the step of encoding represents the choice made by the modeler to assign a formal identity to the semiotic identity of the system to be modeled. Then, a formal inferential system, with axioms, production rules and algorithms, can be used to generate the arrow #3. Finally, the step of decoding (indicated by the arrow #4) makes it possible to use the predictions obtained by the model, based on the use of the chosen formal identity. By decoding, it becomes possible to use simulations based on the behavior associated with the formal identity to predict the behavior of individual realizations. These realizations have to belong to the equivalence class associated with the natural system according to the semiotic identity. Therefore, before using the prediction of a model, it is necessary to validate the model, checking whether or not the predictions may be used effectively as inputs for action.

In the original formulation of the modeling relation Rosen suggests that a valid model should generate a commuting diagram in which the perception given by the arrow #1 should be represented by the three arrows #2 → #3 → #4.

Building on this insight we want to interpret Rosen's theory within the theoretical framework discussed so far. This is illustrated in Fig. 7b. In the theory of modeling relation we are in presence of a process of coupling of two different information paths:

A. Relevant belief about causality in a given narrative: [arrow 1 ← → 1: perception of the story-teller].
B. Effective analysis and data handling based on that belief. The point is to verify whether or not it is possible to build effective prediction: [arrows → 2 → 3 → 4 →: representation in the formal analysis].

In our view, the schematization given in Fig. 7b illustrates clearly the existence of two sets of choices that are logically independent. First is (A) how decide about arrow 1 ← → 1, which includes the pre-analytical choice of a relevant belief expressed within a given narrative about a relevant reality. Pre-analysis is needed when looking for a quantitative model. The second set of choices are about (B), how to decide about achieving congruence among the three arrows → 2 → 3 → 4 →.

The logical independence of choices A and B points to an Achilles' heel of reductionism. The pertinence and usefulness of scientific analysis requires a quality check addressing not only the rigor and efficacy of the formal analysis, but also the choices made in the pre-analytical step determining the relevant perception. The formal analysis is associated with the chosen representation given by the three arrows → 2 → 3 → 4 →. The choices determining relevant perception relates to arrow 1 ← → 1. We expand this point in the following example.

5.2. *Case study: the bifurcations in formal identities used in energy analysis*

Energy analysis as a general discourse has heretofore operated clearly within an agenda set by reductionism. Applications have involved, for example, several assessments of "the energy equivalent of 1 h of labor". These assessments of energy equivalence have all been published in reputable journals, after peer review, and they have been calculated with the required error bars, by reputable experts working in leading Universities. No irony is intended; we ourselves have been lucky enough to have worked with a few of these people and we know them firsthand to be outstanding scientists. Examples of these assessments are: (1) *0.3 MJ* (Norman, 1978); (2) *0.5 MJ* (Revelle, 1976); (3) *1.2 MJ* (Batty et al., 1975; Dekkers et al., 1978; Hudson, 1975); (4) *3.9 MJ* (Williams et al., 1975); (5) *40 MJ* (Pimentel and Pimentel, 1996); (6) *400 MJ* (Fluck, 1981); (7) *20 GJ* (Odum, 1996).

Rigorous scientific assessments of the "energy equivalent of 1 h of labor" found in literature vary from 0.2 MJ to more than 20 GJ, a range of the order of 100,000 times! This problem did not pass unnoticed, and since the 1970s, there was more than one conference on the topic in the series "Advances in Energy Analysis". Also there was a task force of experts selected from all over the world dedicated to study these discrepancies.

Rosen's theory of models, can help explain this mystery. Insight comes from the concepts surrounding possible bifurcations in the meaning assigned to a given label "energy equivalent of 1 h of labor". As illustrated by Table 1, these different assessments of the energy equivalent of 1 h of human labor are based on non-equivalent narratives. Therefore, they refer to non-equivalent descriptive domains. This means that the way energy is defined, measured and represented is itself a variable. This places the analysis in a

Table 1 – Examples of non-equivalent assessments of the energy equivalent of 1 h of human labor found in scientific analyses

Level	Time horizon of assessment	NARRATIVE	Range of values	Energy type	Factors affecting the assessment
n + 3 Gaia	Millennia	EMergy analysis of biogeochemical cycles and ecosystems	10–100 GJ	Embodied solar energy	Ecosystem type Choice in the representation Transformities Choice of ecological services included
n + 1 society	1 year	Societal metabolism	200–400 MJ	Oil equivalent	Energy sources mix Energy carriers mix End uses mix Efficiency in energy uses Level of technology Level of capitalization
n household	1 year	Time allocation	2.0–4.0 MJ	Food energy	Quality of the diet Convenience of food products
	1 year	Technological conversions	20–40 MJ	Oil equivalent	Food system characteristics
n − 2 body/organs	1 h	Physiology	0.2–2.0 MJ	ATP/food energy	Body mass size Activity patterns Population structure (age and gender)

folded non-Euclidean space. That is to say, there are definitions of energy which are based on typologies that are logically independent across the various assessments. Each estimation reflects different perceptions of the reality judged as relevant in different scientific disciplines as they define arrow #1 of the modeling relation. The confusion is made worse by the fact that a common unit of measurement for energy – 1 MJ – tends to hide the obvious fact that 1 MJ of ATP used within human cells is not substantially reducible to 1 MJ of gasoline used in a tractor. As with so many abstractions, the concept of energy has to be considered as a semantic concept. James Kay has defined energy as the ability to induce a change in a given state space. It emerges that it is not possible to generate a substantive assessment that remains valid across scales and across different descriptive domains based on a Kay's conception (Giampietro and Mayumi, 2004; Giampietro, 2006). Any formalization of energetic assessments (e.g. exergy definition), in fact, requires the preliminary specification of an identity of the observation space (Fraser and Kay, 2002). The energy equivalent of 1 h of labor is a semantic concept that admits several legitimate formalizations.

In the example given in Table 1 we can see that physiology, engineering, and ecology each provide an initial and distinctive narrative about how to frame the set of relevant transformations associated with energy accounting. Each discipline defines in its own way the scale for perceiving the relevant mechanisms of energy conversions associated with a hour of human labor and the relative descriptive domain. This defines the framing associated with the arrow #1 on the left of the graph of Fig. 7a. The successive analytical process is to formalize a pertinent analysis, which has to generate a commuting diagram in relation to the three arrows #2, #3, and #4:

A. Desirable/relevant belief and descriptive domain (arrow #1): relevant issues, useful beliefs, relative perceptions using identities about what energy is and what it does.
B. Pertinent rigorous analysis (congruence over arrows #2, #3, and #4): data, models, indicators used to quantify formal identities within the selected descriptive domain.

In this example, it is clear that a check on the quality of the analysis for guiding action has to focus on the quality of the coupling of a given relevant belief and narrative to the relative pertinent analysis. The rigor of the analysis *per se* is not the cause of the inconsistencies.

5.3. *The distinction between models (based on strong semiotic identities) and similes (based on weak semiotic identities)*

The distinction we wish to make here involves an extensive formulation. As an incentive to work through all that formality, let us turn to a simple example that makes the issue at hand readily identifiable. Imagine now that we want to assess the ''average weight of Italian farmers'' to be used in a model. In this example ''Italian farmer'' is the semiotic identity object of our investigation. The empirical work associated with this task requires the ability to measure the characteristics of a significant number of realizations (sample) of such an equivalence class (type). Clearly, if we were including in that sample individual realizations belonging to other ''classes'' such as trucks, whales and refrigerators, we would not get any valid information for calibrating the image of this class in the model. But how to decide, when sampling, what are the criteria that should be used to individuate legitimate members of the class ''Italian farmer''? Should we include in the sample Italian farmers weighting 2 g or 2 tonnes? As a matter of fact, we can decide to exclude from the sample individual realization weighting 2 g or 2 tonnes by saying that Italian farmers must belong to the category ''human being'' (the type Italian farmers is a sub-set of the type ''human being''). But this implies that not all human beings are Italian farmers. Which other criteria should be used to define the equivalence class which has to be used as external referent of the formal identity? If the empirical analysis is aimed exactly at individuating, what are the expected values typical for this class (the image obtained when using only a single proxy variable: body weight). This requires knowing other observable qualities associated with this class, which are not included in this formal identity. These additional observable qualities are needed for it to be possible to individuate realizations of ''Italian farmers'' to be included in the sample. Let us try to synthesize this extended discussion. ''Italian farmer'' is a label used in a natural language (English) to define a given typology of realization to be modelled—it refers to a semiotic identity. However, when dealing with the formal representation of this semiotic identity within a mathematical model, the complexity of this semiotic identity has to be simplified when choosing a very simple image of it. In this example we are dealing with a single observable attribute, which is associated with the weight of each realization. That is the simple image in the model is provided by the value taken by the proxy variable—kg of mass. At this point we have the co-existence of one large set and one small space. The very large set of established and expected information is about the semiotic identity. The identity refers to the equivalence class of Italian farmers that with its activity, on a large space-time scale, made it possible for those using a natural language to build a commensurate experience about this type. The small and finite information space is the formal identity, used to represent the equivalence class within mathematical models. In this case, the formal identity used in the quantitative representation consists of a single variable—the weight of each individual.

This entire discussion is purposefully made to appear trivial, but depending on the goal and the nature of the analysis, it can have large implications. In fact, the label ''Italian farmers'' has different meanings – it maps onto different semiotic identities – for story-tellers motivated by different goals. For example, a marketing company would associate with such a label the meaning ''those farming in Italy and that are potential buyers of products for agriculture''. In this case, the label maps onto a semiotic identity which would include immigrant farmers in the sample. A civil servant working in the Italian Ministry of Internal Affairs would associate to the same label ''Italian farmers'' a semiotic identity which refers to ''those appearing as farmers in the statistical records and holding an Italian passport''. Another story-teller, for example, the head of an ultra-nationalistic

Italian party willing to launch a campaign against immigrant farmers, would associate yet another meaning to this label "those among the farmers operating in Italy that belong to the Italian tradition". According to this definition, only very old people would be included in a sample of organized structures belonging to the semiotic identity associated with the label "Italian farmers". Because of these disparities, different scientists hired by different story-tellers having non-equivalent legitimate interests in assessing the average weight of Italian farmers would be asked to use different procedures of sampling. These different sampling procedures will reflect different interpretations of the label "Italian farmers". The situation is similar to that generating the non-equivalent assessments of the energy equivalent of 1 h of human labor discussed above.

A strong semiotic identity entails the existence of a strong external referent expressing an integrated set of expected attributes for the members of the equivalence class associated with it. For example, the label DOG maps onto a strong semiotic identity. Several non-equivalent formal identities can be associated with both the label and the equivalence class of "dogs" whose validity is easily agreed upon by different social actors. There is an uncontested agreement on a certain set of characteristics to be used to define what should be considered as a dog. Such a definition implies the parallel use of different attributes that are all expected to be presented when dealing with individual realizations of dogs. By contrast, a weak semiotic identity applies when there is a large ambiguity associated with the interpretation of the label—e.g. Italian farmers.

Semiotic identity is associated with "Why?" in the natural system prior to modeling it. Contrast that with formal identity associated with the "How?", when performing a formal modeling of the system. When dealing with a semiotic identity we deal with an open set of relevant qualities which is very large (virtually infinite) and expanding in time. Whereas, when dealing with a formal identity associated with the formal modeling, we deal with a set of proxy variable which is given, finite and fixed over time. The observable qualities considered in the formal identity chosen for the model are only a (very small) sub-set of the potential relevant qualities associated with the semiotic identity of the natural system. That is, in the step of encoding, the modeler must decide how to simplify the semiotic identity of the modeled system by choosing a special formal identity in a large universe of possible formal identities. With the choice of encoding, the modeler is defining an image of the natural system in the model, which reflects only a limited view of it. The "cave allegory" of Plato can be recalled here, who suggests the expression of "shadow on the wall" to convey the idea that the images of the reality that we use in our formal representations are necessarily reflecting only partially the originals (more on this in Filar, 2006). The shadow is all that is left of the natural system in the formal identity.

The main point of this section is that, when establishing a modeling relation, the information associated with the semiotic identity must remain crucial to the operation of the model even after the step of encoding is taken. After the simplification of the representation of the modeled system into a given image, there are still two crucial tasks to be performed. Calibration and validation of the model require both use of observable qualities. These qualities are associated with the semiotic identity of the modeled system, and are not included in the formal identity used in the model. That is the successful application of a model to a given situation requires knowing about observable qualities of the natural system which are not included in the formalization associated with the model.

To clarify this point, imagine that a team of modelers is asked to generate a model useful for predicting the speed of dogs. Let us imagine that for this model they decide to adopt a formal identity of dogs which includes a set of proxy variables represented by: "the number and the length of legs" and "expected relations of the shape of muscles and bones in the skeleton". So as to be able to calibrate such a model, the modelers have to use a measurement scheme sampling a certain number of individuals belonging to the equivalence class of dogs. To establish a valid modeling relation, one must be able to identify legitimate members of the equivalence class "dogs", when sampling for calibration. However, when deciding how to select a certain number of individual dogs to be sampled, individual realizations of dog cannot be chosen on the basis of the formal identity of the model (e.g. the number and the length of legs, expected relation of the shape of muscles and bones in the skeleton). Indeed, this particular formal identity is not specific to dogs. It can also be applied to lions, zebras, and horses. The dogs to be included in the sample have to be chosen using other observable qualities associated with the semiotic identity of the class, which are not included in the formal identity of the model! The same constraint will apply later on, when dealing with the step of decoding. It will apply to both the selection of dogs which have to be sampled to validate the results of the model and the selection of individual realizations of dogs to which apply the predictions given by the model. This represents an additional complication in the operation of a scientific model. The predictive power given by models is based on it being possible to use formalizations referring to perceptions defined at a large scale, for guiding action in relation to local interactions with special realizations. This link to the large scale requires the existence of strong semiotic identities used in the model. Addressing this additional complication, requires exploring more in detail the flows of information taking place during the establishment and operation of a modeling relation.

This peculiar network of flows of information is illustrated in Fig. 8 and it can be related to the general scheme of the modeling relation illustrated in Fig. 7. After having obtained a pre-analytical input about a narrative directed at causality, information is gathered from measurements on individuals supposed to belong to an equivalence class associated with the semiotic identity (e.g. dogs). This information is used to define the image of this natural system according to the formal identity used in the model. That formal identity was established and used in the steps 2 and 5 of Fig. 8. Here the modeler is calibrating the model based on the formal identity using information gathered from the equivalence class. Then the image obtained from the class is used to generate predictions on expected variations of the given image (in the step 3 of Fig. 8) in relation to the selected formal system of inference (e.g. the equations of the model). At this point,

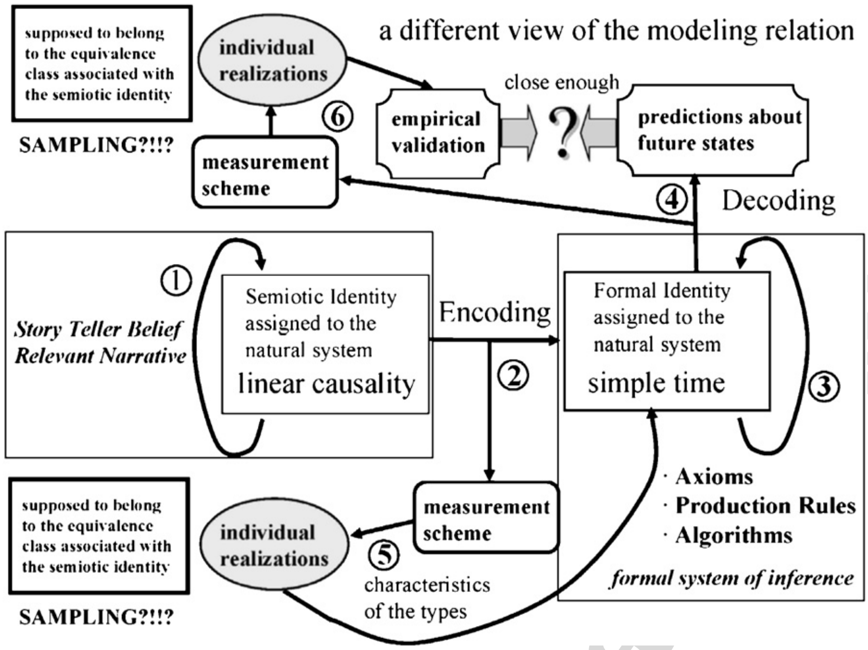

Fig. 8 – The critical differences between models and similes when using a given modeling relation for purposive quantitative analysis.

decoding a valid model should make it possible to anticipate the behavior of those realizations considered legitimate members of the modeled equivalence class. In order to check the validity of the model, it is necessary to sample an adequate number of individual realizations *supposed to belong to the class* and verify the accuracy of the predictions.

The scheme given in Fig. 8 shows again the distinction between the two elements required to obtain a validated model:

- *What is perceived according to the semiotic identity endorsed by the story-teller* → 1 →. The arrow #1 represents the perceived causal entailment defined as relevant by the story-teller within a given semiotic identity assigned to the natural system. The story-teller in this case may represent either a pioneer scientist looking for new understanding or a scientist using the standard framing of the issue within a disciplinary field. Alternatively the narrator may represent the perception of a powerful stakeholder, perhaps the University paying the salary to the modeler.
- *What is expected according to the formal representation of the behavior of an equivalence class—the trajectory determined by the arrows* → 2 → 5 → 3 → 4. The point to be made here is that even though this input is based on the chosen formalization, it still requires semiotic activity. In fact, the full trajectory over these different arrows implies mixing information which derives from the adoption of both semiotic and formal identities in three distinct steps identified in Fig. 8, and laid out below.

Step #1 *encoding*. The information received by the measurements over the sample of elements of the class → 2 → 5 →. In this phase, the equivalence class is the external referent. It is associated with the modeled system – the species "*Canis familiaris*" – which has to be used to define the quantitative characteristics of the image of dogs according to the formal identity adopted in the model. *When encoding the modeler has to fulfill two tasks*. First the modeler must use the given semiotic identity to identify an equivalence class used as external referents to build a model. This equivalence class must express the relevant behavior to be explained. Second the modeler must choose wisely a formal identity to generate an image useful for representing and analyzing the relevant behavior. Coming back to the "allegory of the cave" of Plato, the equivalence class of dogs would represent "the original" which is generating the image. Whereas Plato would suggest that the original is fixed and large in a real external world, we hasten to add that the original is predicated on the interest of the observer. For instance, a much looser class of dog-like animals might perfectly well include a *thylacine*, a recently extinct wolfish marsupial, whose common name is the Tasmanian tiger. The original then would embody the "dogginess" of that species too, along with that of many other dog-like creatures. Thus, the original does not exist independent of the observer, as Plato might imply. The original is predicated upon observer decisions, which are the basis of the meaning of the original.

Step #2 *selecting an inferential system*. Determining the entailment over the values of the proxy variables associated with the model → 3 → 4 →. The selected formal system of inference provides predictions about the expected behavior of the selected types used in the model.

Step #3 *decoding*. The anticipatory power given by the inferential system can be used to make prediction only after validating the model. This requires first the flow of information → 4 → 6. *When decoding the modeler has to fulfill two other tasks*. First the modeler must use the selected inferential system applied to the image of the natural system to generate useful predictions about relevant behavior of the natural system. Second the modeler must use the semiotic identity indicated by the story-teller to identify individual members of the equivalence class to which the predictions generated by the model can be applied.

The point of the foregoing dissection is that, finally, it is possible to discuss the crucial distinction between a ''model'' and a ''simile''. We define a model as any combination of steps generating a commutative diagram in the network of relations indicated in Fig. 8. This implies that it is possible to obtain an uncontested value judgment about four decisions:

(i) What finite set of attributes to select when deciding a formal identity—e.g. it is the formal identity of the equivalence class, used as image in the model, able to capture all the key relevant characteristics for the model, which are associated with the semiotic identity?
(ii) How to sample when calibrating the model—e.g. are the individuals included in the sample used for calibrating the model legitimate members of the equivalence class?
(iii) How to sample when validating the model—e.g. there is an agreement on the criteria to be used to define an effective sampling procedure to validate the model?
(iv) How to decide when the modeling relation is generating a commuting diagram—e.g. are the predictions generated by the model close enough to what is found in the empirical check? Reminded by Box (1979) that ''All models are wrong'', we must admit that such a judgment cannot be a substantive one.

When adopting this definition of model, we note that the vast majority of what are called models in social sciences are not models in the sense defined above. The type of model used by social science and economics is at best a ''simile'', since they are based on the use of weak semiotic identities (Georgescu-Roegen, 1971; Mayumi, 2001; Mayumi and Giampietro, 2006). Recall that weak semiotic identity has a tautology embedded in it, where the model plays a role in defining itself. That is, similes have to handle semiotic identities, which cannot be formalized and validated in an empirical analysis. Such a semiotic identity might be tied to, say, the value of biodiversity, which cannot be identified without generating legitimate but contrasting opinions on how to implement quantitative analysis. When making models in social sciences, the real problem is not to set experimental schemes, such as working out how to count chairs or telegraph poles. Rather, the challenge in the social sciences it is to find strong semiotic identities to be adopted in the model. The challenge is to find robust equivalence classes to be assigned as external referents to formal identities. Forced to use similes, the social sciences are constrained much more than biological sciences by the narrative sitting firmly on the shoulder of the analyst. Standard practice in biology has protocols that generally lead to models in our strict sense, and so the narrative may be unspoken without it becoming mischievous. The presence of inappropriate narratives in economic models can be particularly troublesome, because the mathematical rigor of that discipline tempts the economist to imagine that they can leave the narrative unspoken, as it often is in biology. The focus and rigor involved in working out the mechanics of the Krebs Cycle in biochemistry has an attendant narrative of evolution, which allows a valid application of that finding across much of biology. The same is not true of narratives about an increase in gross national product (GNP) will ''raise all ships''. Increasing the GNP of a small island state may fuels inflation, inequity, destruction of natural capital, and national debt. While biology can benefit significantly from the formality introduced in this paper, the social sciences addressing governance ignore it at their peril.

Whenever we find an ambiguity in the original definition of the semiotic identity of the modeled system, it becomes impossible to verify the validity of a mathematical model based on a formalization of such identity. In fact an empirical validation would require first of all a valid sampling procedure. In turn this would require one to have robust criteria to recognize whether or not the various elements included in the sample are legitimate realizations of the structural and functional type associated with the semiotic identity of the investigated system. When defining the arrow #1 there are several possible interpretations to be given to the semiotic identity of the natural system, these alternative interpretations will generate bifurcations in the interpretation, when defining the criteria of sampling for either the calibration or the validation of the model.

Whenever we deal with a weak semiotic identity associated with concepts such as welfare, justice, quality of life, biodiversity, the empirical side of the analysis is less robust. In a simile the semiotic identity of the modeled system is so weak that the definition of the formal identity used in the model has also to be used for defining what to sample when calibrating and validating it. Thus, a simile entails a tautological definition within the modeling relation. In this case, *the measurement scheme, rather than calibrating or validating the model*, *ends up by measuring what has been defined as the thing to be measured*. When dealing with a concept such as the weight of ''Italian farmers'' in the example that opened this section, the accuracy of the relative measurement of individual realizations is not the most important criterion for checking the quality of the relative quantitative assessment. In this case, the relevance of the accuracy of the assessment of the ''average weight'' of Italian farmers can only be discussed after reaching an agreement among those supposed to use the output of the model, on the meaning of such an expression. Without such a preliminary agreement, numerical differences in the assessment of the weight of ''Italian farmers'' may simply reflect the existence of different meanings assigned to the same label, which have been then translated by the analyst into different sampling protocols. Energy engineers are renowned for their consistency and logic, but they can still become confused by the values of ''1 h of human labor''. Accordingly, social scientists and students of governance are in grave danger of committing serious errors of logic that may cause them to assert confidently action that is counterproductive.

6. Conclusion

Any process of decision making which is based on the use of mathematical models entails the twin procedural problems of:

(1) who should define their relevance, pertinence, usefulness, robustness, accuracy, and (2) how to select the procedure for such a definition (how to decide who should define that). Rosen (2000) makes much of the difficulties embodied in an infinite regress. We have one here, since one needs to select a procedure in order to choose who should select the procedure and *vice versa*. Put in another way, when dealing with the modeling of the evolution of complex adaptive systems, especially when the modeler is part of the system to be modeled, it is impossible to develop substantive rigorous models capable of generating uncontested scientific outputs for guiding action. This is certainly the case when one deals with science for governance, but should not be taken to imply that quantitative analysis should be abandoned in such situations. ''Obviously, there is a danger that legitimate concerns about the use of mathematical models in decision making may bring about disregard for valid findings of well designed mathematical models that are properly used within their limitations. That is, without an agreed upon procedure for validation, it becomes possible that politicians and other decision makers may find it convenient to ignore findings that they should heed. Neglected findings could be about climate change, or levees breaking, or an epidemic spreading, or economic consequences of clearing forests. This is to say, that when dealing with the use of mathematical problems for guiding action, the development of formal systems of inference and the gathering of the relative data cannot be performed in isolation'' (Giampietro et al., 2006). It must be coupled with a simultaneous process of interaction with the society, so as to assure a quality check on the semantic associated with the various formalizations.

Through this paper we have endeavored to dissect apart the complications of modeling and scale. We see these issues as important because continuing to ignore them will lead to a continuance of confusion both in the modeling operation and in the use of models for governance. In the absence of the distinctions made here, modelers are invited to make unwarranted assertions and talk at cross-purposes (e.g. when using the results of rigorous models developed within irrelevant narratives or when confusing ''similes'' for more robust models). Furthermore, they will not generally be aware that they have a problem. If this paper is of service, it is mainly in raising these counter-intuitive issues, so that they may be aired more in public by mainstream modelers and scientists facing complex issues.

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