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Ontology and evolutive genesis of reason

EVOLUTION AND ANTICIPATION

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Introduction: Evolution and Anticipation

Professor Roberto Poli's view is founded on his research background: ontology and system theory. His systemic ontology offers a unitary and holistic approach to understand reality and, most specifically, life. This professor highlights the concepts of anticipation (ability to behave taking into account possible future states), autopoiesis (systems capable of reproducing the components of which they are composed) and self-referentiality (the system's relational self-production governs its capacity to have contacts with the environment) as important characteristics of the life systems. Thus, the seminar began with a discussion of the essential characteristics of life – in relation to the classical question *what is life?* – from an ontological perspective using the conceptual framework of the theory of systems and the relational biology (among others). This discussion has become the first step in our search for the origin and nature of reason, as a special feature that emerged evolutionary within the realm of life.

Several of the challenges of this seminar are to define precisely, if possible, the evolutionary nature of reason and to clarify the causes that led to the emergence of human reason from the cognitive faculties found in animals. The criterion to accept or reject one or other explanatory theory should be the phenomenological experience of reason: in the ordinary human knowledge (the «common sense»), in the exercise of logic expressed in natural language, in the varied types of discourse, in philosophy or in the humanities and in natural sciences. If life has developed in the form of self-referential living systems capable of autopoiesis and anticipation, what are the essential features that reason provides to those living systems we call human beings? Roberto Poli's perspective could contribute to our research with the following two main questions: How and why would evolution favour the development of much more complex self-referential and anticipatory abilities in the hominids, arriving thus to self-consciousness and a cognitive way of representation of the environment and its processes? And what is the essential role (or 'nature') of 'reason' in the holistic system that constitutes each living person?

I. POLI'S FRAMEWORK PAPER: EVOLUTION AND ANTICIPATION

1. Introduction

According to the theory of evolution as initially presented by Charles Darwin, chance variation and environmental pressure are the two factors jointly explaining both the variety of forms of life and their adaptation to the environment where they happen to live. Subsequent research has provided not only overwhelming confirmation of these two factors, but it has also called attention to their insufficiency: something more is needed in order to explain the many subtleties of life. In what follows I shall first briefly present three intriguing cases, respectively addressing the nature of ethical behavior, intelligence and the capacity to foresee the future. The three cases represent only a tiny fraction of the many novelties emerging from contemporary research and which call for a reconceptualization of biology. The last of the three cases will be addressed in some depth, because it the one that most explicitly indicates the way forward to a new vision.

1.1. *The Good Samaritan*

More often than not, most of us think that empathy and compassion are eminently human behaviors, because only a species as evolved as ours has the requisite cognitive abilities, such as the capacity to perceive the pain of other living beings, or even more generally, the problems of other living beings. But that empathy and compassion are not uniquely human is nicely shown by the many cases presented by the primatologist Frans de Walls in his books. The following is one of the most interesting of them:

> «When a bonobo named Kuni saw a starling hit the glass of her enclosure at the Twycross Zoo in Great Britain, she went to comfort it. Picking up the stunned bird, Kuni gently set it on its feet. When it failed to move, she threw it a little, but the bird just fluttered. With the starling in hand, Kuni then climbed to the top of the tallest tree, wrapping her legs around the trunk so that she had both hands free to hold the bird. She carefully unfolded its wings and spread them wide, holding one wing between the fingers of each hand, before sending the bird like a little toy airplane out toward the barrier of her enclosure. But the bird fell short of freedom and landed on the bank of the moat. Kuni climbed down and stood watch over the starling for a long time, protecting it against a curious juvenile. By the end of the day, the recovered bird had flown off safely» (De Waal, 2005, p. 2).

It is convenient to quote the subsequent words by de Waals:

> «The way Kuni handled this bird was unlike anything she would have done to aid another ape. Instead of following some hardwired pattern of behavior,

> she tailored her assistance to the specific situation of an animal totally different from herself».

The evidence that empathy and compassion can be present in other species shows that the roots of ethics are deeper than is commonly believed.

1.2. *Intelligence*

Recent research on plants shows that we may have to change otherwise deeply entrenched beliefs. Whatever the wonders of the vegetable realm, plants are anything but intelligent creatures. In fact, common sense assumes as axiomatic the equation vegetable = brain-dead. Being reduced to (the situation of) a vegetable is one of the worst things that can happen to any of us. Aside from the appropriateness of the analogy, the problem is whether plants are in fact as unintelligent as is usually assumed.

The picture emerging from the research conducted during the past ten years holds numerous surprises. The main one is that having a brain is far from being a necessary condition for exhibiting intelligent behavior. If intelligence is defined as an organism' s capacity to detect signals and to adjust its behavior to them, plants are definitely intelligent beings. One of the main outcomes of research is that there are many different forms of intelligence, including species, bacterial, protozoan, genomic, immune, swarm, metabolic and animal intelligence (Trewavas, *Aspects of Plant Intelligence: Convergence and Evolution,* 2008, pp. 73-78). Furthermore, «apart from the higher animals that use the centralized activity of the brain to process information and in which classical intelligence is located, *all other biological systems possess a decentralized intelligence that is a consequence of behavior by the whole system* [involving] a network of interacting constituents of varying degrees of complexity, whether it be molecules, cells, or individual organisms, *through which information flows* (Trewavas, *Aspects of Plant Intelligence: Convergence and Evolution,* 2008, p. 79).

Let me further quote some passages from the survey conducted by Trewavas, *Aspects of Plant Intelligence: Convergence and Evolution,* 2008; see also Trewavas, *Aspects of Plant Intelligence,* 2003, and Trewavas, *Aspects of Plant Intelligence: An Answer to Firn,* 2004:

- Resources (light, minerals, and water) figure strongly in a signals list that also includes numerous mechanical influences such as wind, rain, and touch; gases such as ethylene and nitric oxide; soil compaction and particle structure; and numerous biotic features, such as identity of neighbors and disturbance, among many others.
- Plasticity helps to deny resources to other individuals by active competition.
- The individual plant also modifies its own environment by continued resource exploitation and growth.
- Present signals are used to predict likely future changes in resource supply.

Two aspects seem peculiarly outrageous, namely: the recourse to the category of individuality in such situations as competition between individuals, with its implied exploitation of their identity, and the reference to anticipatory or foresight capacities exhibited by plants.

That plants have some sense of identity is demonstrated for instance by the behavior of their root system. Not only is there «strong spatial segregation between the separate root systems», but «competitive roots of different individuals, growing within the vicinity of each other, avoid direct contact and can cease growth if contact is forced» (see Trewavas, *Aspects of Plant Intelligence: Convergence and Evolution,* 2008, p. 86, and the other sources there listed). Furthermore, «there is strong evidence that plants actively compete for space itself and are territorial, vigorously occupying local space to deny it to others». By dividing a plant into separate clones, it has been shown that it takes time for the various clones to forget their common origin, and they only start to regard each other «as aliens within a few weeks of separated growth» (Trewavas, *Aspects of Plant Intelligence: Convergence and Evolution,* 2008, p. 87).

Anticipation will be dealt with in the next section. For the time being, I merely note that plants show a surprising «ability to anticipate environmental change, even though it may not happen during the lifetime of the individual plant» (Trewavas, *Aspects of Plant Intelligence: Convergence and Evolution,* 2008, p. 90).

Before leaving this section, three final observations are mandatory. First, the main reasons explaining why the phenomenon of plant intelligence has escaped attention until very recently are, first, that the time scales used by plants are widely different from the time scales of animals. Second, cleverness is exhibited by plants «under conditions that mimic those in the wild». It follows that intelligence is an evolutionary benefit useless for domesticated species, whose morphology and behavior have been restricted for our benefit. Indeed, no domesticated species would be able to survive in the wild, competing with other more behaviorally adept – i.e. intelligent, among other things – species (Trewavas, *Aspects of Plant Intelligence: Convergence and Evolution,* 2008, p. 70). Third, the intelligence of plants is based on their capacity to sense the totality of their environment, with the response to an assessed change in any one signal being synergistically modified by all the others (Trewavas, *Aspects of Plant Intelligence: Convergence and Evolution,* 2008, p. 83).

1.3. *Anticipation*

Biology is one of the fields in which anticipation has been most extensively studied. Over the past few decades, an enormous amount of experimental evidence in favor of anticipation as a behavioral feature has been accumulated. The hunting habits of snakes and dogs are as good a starting point as any. Snakes search for a prey where it was last sensed. On the other hand, dogs hunting a prey do not need to sense it continuously: dogs are able to anticipate where their prey will be (Sjölander, 1995).

Studies on anticipation in animals describe two main phases of development (Hoffmann, 2003). The first is centered on Tolman's «expectancies» (Tolman, *Purposive Behavior in Animals and Men,* 1932; Tolman, *There is More Than One Kind of Learning,* 1949). One of Tolman's major findings was that of *latent learning* in rats, i.e. learning of environmental structure despite the absence of reinforcement. The studies conducted by Tolman, however, had little impact, and the study of anticipatory behavior in animals started to spread only in the 1980s (see Hoffmann, 2003, for extensive references).

Two very recent studies are worth mentioning. It has been shown that scrub-jays are able to make provision for future needs. As a recent report to *Nature* says: «the results described here suggest that the jays can spontaneously plan for tomorrow without reference to their current motivational state, thereby challenging the idea that this is a uniquely human ability» (Raby, Alexis, Dickinson, & Clayton, 2007, p. 919). Animals do not save food alone: apes, for instance, save tools for future use (Mulcahy & Call, 2006).

Given that anticipatory behavior dramatically enhances the chances of survival, evolution itself may well have found the way to impart anticipatory capacities to organisms, or at least to some of them. The real issue is not whether living systems are anticipatory systems, but which systemic features make anticipation at all possible.

This question immediately brings in Robert Rosen and his theories, which addressed the problem of «what is life?» (for two recent summaries of aspects of Rosen's work see the collections Baianu, 2006, and Mikulecky, 2007). Rosen came across anticipation while trying to spell out the features of life in detail (for more information see Louie, 2009; Poli, *The Many Aspects of Anticipation,* 2009, and Poli, *The Complexity of Anticipation,* 2009).

2. Physics and Biology

Given the many surprises brought by the research of the past few decades, it is advisable to clear our minds and start again. However trivial it may appear, the first step is to make explicit the nature of the connections between physics and biology. This connection has two main components. First, quantum theory works perfectly well for biology as well, i.e. there are no grounds for denying that the framework of quantum theory extends to encompass organisms (Elsasser, 2nd ed., 1998). The simplest way to support this apparently bold claim is to cite the fact that our understanding of chemistry is based on quantum theory; and without chemistry there is no biology. The first claim therefore extends the range of application of quantum theory to the field of organisms. Nothing biological will disconfirm quantum theory. The second claim constrains the previous thesis by specifying that quantum theory is not enough to understand life: something more is needed, something that is widely different from but not contradictory to quantum. Within the theory of levels of reality, the two claims of categorical continuity and novelty constitute the simplest relation between levels, usually called the overforming relation (see Poli, *The Basic Problem of the Theory of Levels of Reality,* 2001; Poli, *First Steps in Experimental Phenomenology,* 2006, for further details).

The simplest way to see that biology requires its own categorical framework is to perform a couple of simple calculations. From the point of view of organic chemistry, living tissue is composed (up to about 99%) by four types of atoms alone, namely C, O, H, and N. Furthermore, between any two adjacent atoms there can be one of three possible ties, namely single bond, double bond or no bond at all. Thus far, things are pretty straightforward. However, as soon as we consider the number of patterns that can arise from the collection of atoms composing a single cell, the number that results is extraordinarily large (Elsasser, 2nd ed., 1998, p. 4). Given that a cell may comprise 10^12 atoms, the state space of the possible combinations comprises 10^12^4^3 patterns, which is one of those finite numbers that extend beyond imagination.

The second calculation proceeds along a similar avenue. Consider the four molecules that make up the DNA. These form the twenty-odd amino acids which in their turn form the proteins. Let us assume that a protein is composed of a hundred amino acids (a very cautious estimate). Now, the combinatorial space arising from these numbers is 20^100 ca, which is equivalent to 10^130 (Conway Morris, 2003, pp. 8-9).

Both calculations yield the same qualitative result: there are far too many combinations. In both cases, the numbers obtained are much larger than the estimated number of particles composing the whole universe (estimated to be 10^80). These numbers are «uncomfortably large» as (Conway Morris, 2003, p. 9) aptly puts it.

Interestingly, however, those combinatorial state spaces are almost entirely void: only a «comfortably» tiny fraction of those spaces has actually been explored by life. Organisms use only a tiny fraction of the theoretically available state space. There are a number of reasons for this state of affairs. Most of the combinations are unsuitable for life because, for instance, they generate chemically inert molecules or insoluble molecules. Conway Morris furnishes a very clear summary of the situation: «Let us then suppose that only one in a million proteins will be soluble, a necessary prerequisite for the watery milieu of a cell… of these again only one in a million has a configuration suitable for it to be chemically active… how many potentially enzymatically active soluble proteins… could we expect to be available to life? … the total far exceed the number of stars in the universe» (Conway Morris, 2003, p. 9).

The conclusion to be drawn from these initial data seems rather obvious: that there is a difference between quantum theory and biology; a difference that does not invalidate quantum theory but requires something new that cannot be explained by the former theory. An explanation may reside in the striking difference between the combinatorial amount of possible physical/chemical cases and the remarkably small sections actually traversed by biological phenomena.

How to find properly biological laws is one of those slippery questions that one does not know how to frame. In fact, classically analytic frames of analysis do not present themselves as suitable candidates (Poli, *Analysis-Synthesis,* 2009). The theory of evolution is the best starting point currently available, but it is itself in need of further developments, as shown by the three cases presented at 1.1-1.3 above. Apart from selection and adaptation, it is apparent that evolution tends to work conservatively by exploiting already available 'building blocks', instead of incurring the risk of drawing up new plans (Conway Morris, 2003, p. 8). This implies that evolution tends «to arrive at the same 'solution' to a particular 'need'» (Conway Morris, 2003, p. xii). It is worth mentioning at least a couple of examples from the extensive list provided by Conway Morris, namely the camera-like eye and agriculture.

Eyes have evolved independently very many times (Conway Morris, 2003, p. 164). The camera-like eye, in particular, «has evolved independently at least six times» (Conway Morris, 2003, p. xii). To be noted in this regard, is that there are also cases of brainless animals (e.g. jellyfish) that have been able to develop camera-like eyes. «Seeing without a brain has certainly attracted notice, although» there are even more surprising cases, such as those of organisms that «have an eye that evidently can focus an image without even the benefit of a nervous system» (Conway Morris, 2003, p. 155). This example is interesting in many ways. One of them is the comparison to be drawn between seeing within a brain even without a nervous system and the capacity that organisms may have of exhibiting intelligent behavior even if they lack brains and nervous systems.

The second example of convergence is agriculture, which is something apparently unique to humans. Let me quote: «To become a farmer entails a series of familiar processes, from maintenance of gardens, transport, weeding, application of herbicides, manuring, cropping, to the exchange of cultures. That is effectively how we pursue our agriculture. So, too, and convergently, do the leaf-cutting ants [Acromyrmex and Atta] that flourish in Central and South America» (Conway Morris, 2003, p. 198). Again, evidence is provided that any given problem has only a limited set of solutions, and convergence shows that working solutions are discovered time and again.

3. Relational Biology

The findings cited thus far show that the theoretical framework of biology needs a structure richer than variation and selection alone. Here I would like to explore the path opened by relational biology, a minority trend developed by a small group of mathematical biologists, such as Nicolas Rashevsky (1st generation), Robert Rosen (2nd generation) and Aloisius Louie (3rd generation). The recent (Louie, 2009) is the clearest and most updated presentation of their framework.

Relational biology is in many ways similar to, but more general (and precise) than, the better known idea of autopoiesis. The viewpoint of autopoiesis is that wholes that are organisms have original features different from those characterizing other types of wholes. In short, autopoiesis is the capacity of a system to reproduce the components of which it is composed. A multicellular organism thus generates and regenerates the very cells of which it is composed; a unicellular organism generates and regenerates the components of the cell (Maturana & Varela, *Autopoiesis and Cognition,* 1980; Maturana, *Autopoiesis,* 1981).

Autopoiesis dramatically modifies system theory. An autopoietic system does not start from pre-given elements, nor does it assemble them. Furthermore, autopoiesis does not come in degrees: either a system is autopoietic or it is not. For an autopoietic system, the classical distinctions between system and environment and between closed and open systems acquire a new valence. Autopoietic systems are self-referential systems, meaning that the system's relational self-production governs the system's capacity to have contacts with its environment. Put otherwise, the system's connection with its environment is no longer a kind of immediate and direct relation between the system and its environment but becomes a reflexive relation, mediated by the self-referential loops that constitute the system itself.

As far as autopoietic or self-referential systems are concerned, the guiding relation is no longer the «system ↔ environment» duality, but «system ↔ system» intra-relations, or automorphisms. For autopoietic systems, the classic difference between open and closed systems – where open means that the system's boundary is porous and lets both the system and its environment exchange matter and energy – acquires a new and different meaning: *openness* maintains the previous meaning of exchange with the environment, whereas *closure* now means the generation of structure, understood as the set of constraints governing the system's internal processes. Closure (or structure), then, organizes the system as a *holon*, or integral whole. The guiding connection changes from the system-environment connection to that between the system and its own complexity, understood as the system's capacity to adjust its own functional organization and internal structure (for further details and the connection with social systems see Poli, *The Complexity of Anticipation,* 2009).

The above-described features of autopoiesis are shared by relational biology, which adds further and even deeper understanding of the nature of organisms.

Rashevsky set the tone: «to understand life, throw away the matter and keep the organization». To make things worse, Rashevsky's claim, however bold it may at first appear, must be taken literally: life is not to be found in any of the many physico-chemical machineries exhibited by organisms. What is properly biological (i.e. alive) can be seen only at a higher level of abstraction. After Rashevsky, Rosen found the minimal structural properties able to define life itself, which were then further developed and explained by (Louie, 2009).

Rosen's main idea is that a living organism is a system closed to efficient causality. That is to say, all the processes unfolding within an organism are mutually entailed. An organism is a system such that the causal entailment from A to B, and then from B to C, and so on and so forth is such that sooner or later there will be a causal entailment entailing A itself. In other words, organisms are causally closed systems (an idea shared by autopoiesis), at least as far as efficient causation is concerned. More discursively, the thesis is that all the processes unfolding within an organism are mutually linked to each other.

The claim that all dynamical processes within an organism are linked and entangled with each other implies that organisms are self-referential or impredicative systems. The thesis of impredicativity has wide consequences, one of the most important being that all the information describing an organism will never be completely captured by any algorithmic (i.e. mechanistic) model. The already mentioned (Louie, 2009) provides the relative technical details.

4. Anticipation

The mainstream wisdom claims that causes move things forward. As solid and reassuring as this statement may be, it nevertheless runs into trouble as soon as phenomena of self-organization or network causality are taken into account, such as Rosen's claim that an organism is a system closed to efficient causation. What kinds of causality are these? Matters become worse when the emergence of hierarchies – i.e. levels of organization – are considered. Even if hierarchies may emerge from the bottom up, the higher levels usually exert some kind of top-down constraining influence on the lower levels of the hierarchy. To say the least, downward causation is far from being part of the received wisdom. The hierarchical loops emerging from the cycles of up and down causations between hierarchical levels are even farther away from the mainstream. When hierarchies further assume the form of different, possibly tangled, levels of reality between different types of entities – atoms, molecules, organisms, minds and societies – it is obvious that something important has been missed by mainstream theories of causation (Poli, *The Basic Problem of the Theory of Levels of Reality,* 2001; Poli, *Three Obstructions: Forms of Causation, Chronotopoids, and Levels of Reality,* 2007).

The capacity of anticipation patently shown by organism makes things even worse. Anticipation is the most important aspect missing from mainstream theories of causation. Behaving in an anticipatory way means adjusting present behavior in order to address future problems. In other words, an anticipatory entity (system or whatever) takes its decisions in the present according to forecasts about something that may eventually happen.

The best-known definition of anticipation is still Rosen's: «An anticipatory system is a system containing a predictive model of itself and/or its environment, which allows it to change state at an instant in accord with the model's predictions pertaining to a later instant» (Rosen, *Anticipatory Systems. Philosophical, Mathematical and Methodological Foundations,* 1985, p. 341).

The most obvious mistake committed by almost everyone when first confronted with the idea of anticipation is to think that anticipation is a feature that *we* possess because we are such highly complex and wonderfully sophisticated cognitive agents. This is not what the theory of anticipation claims. Indeed, the major surprise embedded in the theory of anticipation is that anticipation is a widespread phenomenon present in and characterizing all types of realities. Life in all its varieties is anticipatory: the brain works in an anticipatory way, the mind is obviously anticipatory, society and its structures are anticipatory, even non-living or non-biological systems can be anticipatory. And this is more than a surprise.

If all this is true, and providing that the necessary supporting evidence can be accumulated, it follows that a proper understanding of anticipation requires the adoption of an innovative conceptual framework. Moreover, this new framework will have to be innovative in many different ways, some of which will be mentioned by this paper.

As soon as one starts collecting data on anticipation, the first surprise is the finding that over the past century many scholars from many different disciplines and fields have worked on anticipation. The unwelcome result is that nobody has to date collected and compared the various proposals. It may well be that the same phenomenon has been discovered time and again. Even so, it would be interesting to know the differences, if any, among the theories. It may be that different scholars have seen different aspects of anticipation, and a thoroughgoing comparison among them may help develop a more rounded-out theory (for an overview, Poli, *The Many Aspects of Anticipation,* 2009).

5. A Model of Anticipation

In what follows I shall closely follow Rosen's discussion in describing the basic structure of the simplest anticipatory system.

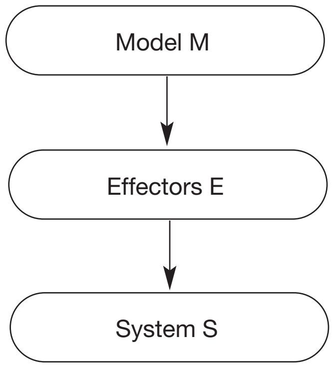

Figure 1

Let us start from any system S whatever. S may be an individual organism, an ecosystem, a social or economic system. For simplicity I assume that S is an ordinary (i.e. nonanticipatory) dynamical system. A second system, called a model M of S, is then associated with M. The only preliminary condition that must be assumed is that the dynamic evolution of M proceeds faster than the dynamic evolution of S. In this way, M is able to predict the behaviour of S. By looking at M we obtain information about a later state of S. So far nothing is really new.

The real novelty arises when we assume that M and S can interact with each other, i.e. that M may affect S and S may affect M.

The direction from S to M can be seen as an updating or an improving of M. This direction is rather straightforward; its analysis can be omitted. On the other hand, the opposite direction from the model M to the system S is much more intriguing.

In order for M to affect S, M must be equipped with a set of effectors E, which allow M to operate on S (or on the environmental inputs to S) in such a way as to change the dynamics of S.

Figure 1 depicts in a hyper-simplified way (e.g., without considering either the environment or the upgrading of M) the logical connections among S, M and E.

If we consider the three systems as parts of one single system, the latter will logically be an anticipatory system in which modelled future behaviours determine present states of the system. As Rosen said «M *sees* into the future of S, because the trajectories of M are faster than those of S» (Rosen, *Planning, Management, Policies and Strategies: Four Fuzzy Concepts,* 1972).

A simple question will aid understanding of the connections among M, E and S: How can the information available in M be used to modify the properties of S through E? Consider partitioning the state space of S (and hence of M) into desirable and undesirable states. As long as the dynamics of M remain in a desirable region, no action is taken by M through the effectors E. When the dynamics of M move into an undesirable region (implying that the dynamics of S will later move into the corresponding undesirable region) the effectors are activated to keep the dynamics of S out of the undesirable region.

Understanding the working of the system enables systematic analysis of the ways in which the system can go wrong. A system of this type can go wrong for various reasons, e.g. for technical reasons (ignoring relevant state variables, wrong specification of its internal dynamics), or for a wrong correspondence between the states of system S and the states of the model M. As far as effectors are considered, they can be bad because they may be unable to steer S, or may fail to manipulate the variables of S appropriately.

6. Comparing Anticipation and Life

Summarizing what we have thus far obtained, we can now distinguish anticipation from life. Both are properties that some systems exhibit. Anticipation as defined by Rosen is based on the presence of an internal model: only systems with internal models have the structural capacity to behave in an anticipatory fashion. The requirement is not advanced that the system be aware of its internal model(s): the models may well work below the threshold of consciousness. When they emerge into conscious purposiveness they contribute to the distinctive quality of causation within the psychological and the social realms. On the other hand, most biological systems are better characterized by non-representative types of anticipation.

Having a model implies, as we have seen, the presence of a causal loop within the overall system linking the three components named S, M and E. Two main consequences arise from this more abstract description. The first consequence is that the main distinction between anticipation and life is that anticipation involves only some of the system's internal causal entailments, while life involves all the system's internal causal entailments. The second consequence is that there is no reason to believe that anticipation is limited to living systems: many different types of systems can have appropriate internal causal loops.

7. Two Strategies

Most readers will possibly appreciate a less abstract description of anticipation. The following question may then arise: What steps should have been realized by evolution in order to let systems become anticipatory systems? As far as I can see, two main answers are possible.

7.1. *The Engineer's Answer*

An engineer would approach anticipation by asking which types of controllers make anticipation possible. On considering the problem of the regulatory structure that a system may have, Rosen was able to distinguish five different types of controller. In order of complexity, the five cases are the following:

1. System with feedback controllers.
2. System with feed-forward controllers.
3. System with feedback controllers with memory.
4. System with feed-forward controllers with memory.
5. System with general purpose controllers.

Feedback controllers «perceive» the system's environment. The most important characteristic of feedback controllers is that they are *special* purpose systems: for them only highly selected aspects of the environment are relevant. Given some selected value, feedback controllers steer the system in order to force it to maintain that value. This is achieved by error signals indicating the difference between some fixed value and the actual value of the selected environmental variable. Within limits, the controllers in this family neutralize environmental variations and are able to keep the system stable. Their main limitation is due to the delay between environmental change and system adjustment: if the changes in the environment happen too rapidly (the exact meaning of «too rapidly» depends on the type and sensitivity of the controller) the controller ends up by tracking fluctuations and rapidly loses its capacity to steer the system.

Unlike feedback controllers, feed-forward ones «perceive» the controlled system, not the environment. The simplest way to imagine a feed-forward controller is to think of a model of the system, as in Figure 1 above. In other words, a material system with a feed-forward controller is a system containing a material model of itself. In order to behave as a feed-forward controller, the model should run at a velocity faster than the velocity of the system. In this way the model anticipates the possible future state of the system.

The third class of controllers comprises feedback controllers with memory. If a feedback controller is able to leave a trace of the system's experience, this memory trace can be used to tune the system's behavior better. A system with this capacity is obviously able to learn from its past experience.

The next class of controllers consists of feed-forward controllers with memory. As in the previous case, systems of this type can learn from their past experience. Rosen notes that systems of this type – «ironically», he says – must use feedback controllers of type 1 for their operations. In fact, they must be able to work on deviations from predicted states (i.e., they need error signals, exactly like type 1 controllers).

The last type consists of systems with general purpose controllers. All the controllers discussed so far can be described as working on single types of «perceptions» or variables. The obvious next step is to let systems behave in as articulated a way as possible (i.e., exploit as many variables as possible). The only constraints are given by the unavoidable need to use feedback controllers to modify the internal models of systems with type 5 controllers (Poli, *An Introduction to the Ontology of Anticipation,* 2009; Poli, *The Complexity of Anticipation,* 2009).

7.2. *The Biologist's Answer*

The second type of answer, let us call it the biologist's answer, is even more interesting than the engineer's, because the former will simply say: nothing. There is nothing that needs to be done to implement anticipatory capacities within a living organism because all that is needed is (implicitly) contained from the very beginning in the working of a living system. Provided that Rosen's definition of organism is accepted, namely that an organism is a system closed under efficient causation – a system such that all its processes are mutually entailed – a living system already is, from the very beginning, an anticipatory system – a system, that is to say, such that some of its processes are mutually entailed. Eventually, what must be verified is whether the entailments are of the appropriate type. One way for them to be appropriate is to follow the S-M-E framework – which was called the simplest possible implementation of anticipation. There are other possibilities, however, such as the construction of specialized modules. The brain is possibly the most relevant case of an organ that systematically works in an anticipatory fashion (Berthoz, 2003). Perception, too, is systematically anticipatory (for a recent statement see Streeck & Jordan, 2009; Jordan, 2009).

8. Conclusion

The most relevant outcome emerging from relational biology is the capacity to see life from a very abstract – even rarified – point of view. Only at this level of abstraction does one have the capacity to detect patterns that disappear from sight when one conducts highly detailed, concrete analyses. Both are unquestionably needed.

Apparently disconnected – even otherwise incomprehensible – data may become more transparent, occasionally even trivial, when seen «from above». Anticipation is possibly the most relevant of these cases.

Whatever the merits of contemporary biological research, its most obvious weakness is its almost complete lack of theory – the lack of a theory of organisms, as (Elsasser, 2nd ed., 1998) was wont to say. It seems to me that relational biology provides a first step towards the development of a theory of organisms, as I have tried to show for anticipation.

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II. SESSION PROCEEDINGS

PRESENTATION

Prof. Javier Leach presented the project Sophia-Iberia, the objectives of its first Academic Seminar, and the profile of Prof. Poli as an invited professor of the first session of this Seminar and then gave the floor to Roberto Poli (for more information, see the power point presentations of Javier Leach [1] and Roberto Poli [2]).

Professor Poli stated at the beginning of his talk that he would not address explicitly the problem of reason, but would stay on its lower boundary and discuss the basic question: *what is life?* The answers to this question would then have some interesting consequences.

First he wanted to present three surprising cases within the field of biology; trying to show in which way life is different from its basis, even without contradicting quantum law nor chemical constraints. Roberto Poli wants to identify the differences that distinguish biology from physics and chemistry, at least to attempt the beginning of a possible answer. He stated that he would also present a new line of thought, relational biology, which, although not always well accepted by main-stream biologists, offers interesting points for reflection. His talk called attention to the anticipatory feature of living systems, arriving at

[1] LEACH, JAVIER, http://sophia-iberia.pbworks.com/f/Presentation_Sophia-Iberia_1st%20academic%20seminar%20-%20JL.ppt

[2] POLI, ROBERTO, http://sophia-iberia.pbworks.com/f/Evolution%20and%20Anticipation_Poli_.ppt

the conclusion that living organisms are essentially impredicative or self-referential systems.

The three surprising cases were:

— Compassion and empathy towards other living beings are not uniquely human; we find something similar in other species (for example the case of a female ape of the Bonobo species showing a caring behavior towards a bird). This fact would lead us to think that the roots of ethic behavior are probably deeper than is usually expected.
— Common sense considers plants as brain-dead. But if we define 'intelligent behavior' as the capacity to recognize problems and face them by taking decisions to solve them, then plants show 'intelligent behavior'. This would mean that having a brain is not a necessary condition for having 'intelligence'. Among the different forms of intelligence we could find a type of decentralized intelligence, working in plants and other organisms, as opposed to the centralized intelligence of animals with nervous systems and brains. Plants also show some sense of identity and anticipation in their behavior. This is not so easy to detect because of their different time scale and because it works mainly in the wild and not in domesticated (observable) environments.
— Anticipation. Human beings usually make plans for the future, but nowadays the claim is that all living systems are anticipatory, showing some kind of feeling of the future (not all of them cognitive-based). Anticipation is an obvious tool that Nature needed to invent sooner or later in order to help survival, because at any given moment the future possibilities for a living organism are too many and decisions must be made in a short time.

Life has some underlying structure, it does not contradict quantum mechanics nor chemistry, but it is not explained exclusively by them either. Something more is needed. For instance, the case of DNA: it is formed by some twenty amino acids, that are the basis for the formation of proteins, but of all the incredibly numerous possibilities of combination of these amino acids only a very small number actually appears in living cells. For this situation to be so severely constrained, Poli assumes that some properly biological law, still unknown, should be at work.

He then presented the point of view of relational biology as developed by Rashevsky, Rosen, and Louie. These authors defend that in order to understand life we have to forget about all its physico-chemical machineries as these do not explain the higher levels, which are specific of life. Looking at the structure of organisms, we find that they are wholes containing parts. But the most specific characteristic of living organisms is that they produce their own parts within themselves. The organisms are alive as long as they are able to maintain this production of their necessary parts. This property is also denominated «autopoiesis» by other scientists. The relational biologists have developed formal models that allow for further in-depth analysis.

Another aspect of life's autopoietical property is its self-referentiality, which is difficult from a formal point of view, because it makes it impossible to develop a complete model. All its formal representations or models would be only partial models. There is no possibility to obtain a complete algorithmic model of an impredicative system.

Back to anticipation, Poli presented Rosen's definition of it: «*An anticipatory system is a system containing a predictive model of itself and/or its environment, which allows it to change state at an instant in accord with the model's predictions pertaining to a later instant*». The system's model runs at a quicker pace, and can thus predict what may eventually happen to provide useful information to the system. As a simple example: if the model distinguishes between positive and negative states, and it sees that the system's dynamics are leading it to the negative region, it then informs the system that it would be better to change something and modify its direction. Of course the model does not always predict the future unfailingly and the system does not always behave accordingly. There are quite a number of possible problems to consider: a wrong model, one unable to steer the system, one in need of updating, etc., but the theory contemplates all these cases too. The important fact is that the system is enabled to take into account future possible states into the present behaviour.

Prof. Poli finished his presentation at this point, so that there would be time for questions. Javier Leach invited the attendees to make some brief questions, reminding them that there would be a more in-depth debate with Prof. Poli the next day.

First Questions

ADOLFO CASTILLA: *Using new names for well known behaviours. Impossibility of predicting or even explaining living systems and human beings exclusively with science.*

ADOLFO CASTILLA brought up that, in his opinion the three curiosities that Poli had mentioned as data worth to take into account to change our point of view about the behaviour of certain living entities were well known from long ago, but they were just receiving new names: *a)* Compassionate behaviour in animals had been already recognized, but the new situation comes from calling it 'wisdom'. *b)* Plants adapting to environment was also a well known fact, but why should we call it 'intelligence'? *c)* We know all biological systems are purposeful, but Poli uses instead the word 'anticipation'. These new names are the ones changing the perspective. He further pointed out that there is no way to prepare a model or create an algorithm able to forecast the behaviour of living organisms or societies, so that we cannot predict them, what makes us finally unable to capture reality. From this fact, Adolfo Castilla assumed that we cannot formulate laws explaining life systems, those which act on themselves. So he asked Poli if he would agree that science is not the right approach to explain living systems and human beings.

ROBERTO POLI said he had not used the term 'wisdom', but 'intelligence' and 'anticipation'. He was trying to show that ethical behaviour is not limited to human beings, even if this idea is not so new. He also agreed entirely on the impossibility of capturing the future. But he affirmed that there are anticipatory structures within the living entities, which are not exactly purposive structures. He usually distinguishes two types of anticipation: one is cognitive-based anticipation (that could be purposive, as when we make a plan) and then the real novelty is that there are other types of anticipation, which work below the threshold of awareness, not related to the mind but otherwise ingrained in the organism. Nobody is claiming that an anticipatory system has to be successful predicting the future. Nevertheless these structures have been invented by Nature in order to help organisms make decisions (maybe automatically and unaware); it is a way of shrinking the possibilities to choose from, giving the organism a better chance to survive. This mechanism has been shown to be rather successful when most species have survived for a long time. But what Prof. Poli would like to emphasize as a novelty that may result in something that will change our way of doing science is that there is evidence that at least some systems are self-referential. If this is true the classical reductionistic way of breaking a system into pieces in order to understand how it works is no more a completely acceptable strategy, even if we accept its enormous success as the way science has been elaborated so far and are grateful for it. But the organisms might present at least in part holistic features and eventually maybe also the mind and the social systems have this kind of holistic structure (a sociologist has defended that social systems are similar to biological systems in this characteristic of being self-referential). If this is true, the methodology for understanding them should be different from an analytical methodology.

ADOLFO CASTILLA stated his full agreement.

JAVIER MONSERRAT: ***How to relate system theory to the explanation of knowledge?***

JAVIER MONSERRAT took first into account Poli's philosophical and scientific background work on ontology and system theory. His talk had been centered about what life is, offering us answers in connection with two main concepts: autopoiesis and anticipation. Then Monserrat affirmed that reality's ontology is clearly systemic, it is a system and also a structure, saying that it would be interesting to determine what the difference is between these two similar concepts, 'structure' and 'system'. Anyway, if we do not talk exclusively about purely material physical reality, but also about living beings we can describe these living systems from an objective point of view and say that life is a system with autopoietic and anticipatory actions. Agreeing with all these ideas, Monserrat tried to identify some important questions for the seminar's subject and proposed that it would be interesting to relate system theory with the nature of knowledge, not only in humans but also in animals (even primitive organisms such as amoebas). The question is how this system theory could be related to epistemology or to the classical explanation of knowledge. Could we say, for example, that intelligence is the ability of a living being to analyse reality as a system? We could also try to relate intelligence to system analysis, asking, for instance, in what way a human and an animal are able to perform this system analysis and what would be the difference between them. A further question could also be: would the difference be in level, in quantity or rather in quality? Finally, it was pointed out that this matter could be discussed in more depth during the next day's debate.

ROBERTO POLI recognized that these are big questions and he could not pretend to give complete answers. The most obvious difference between human beings and other type of living entities is, in his opinion, represented by language and its capacity to organize things. But for him it was more relevant to indicate that there are two basic theories explaining the interaction between a living system and its environment: the classical answer about perception is that stimuli arrive to the organism and then the brain acquires them and makes all necessary elaboration, thus getting the available information about the world (defended by 99.99% of actual cognitive scientists). But if Poli's anticipation theory is correct, the way in which perception works might be different. The perception of the world would be an active process, according to the kind of actions to be performed. We could say that systems are already oriented to the environment in a determined way and are able to select, modulate or modify the incoming information. Perception would then be the modulation of something that is already ongoing: there is a global activity of the organism, and the interaction with the environment modifies what is already going on within it. If this is so, it would force us to change in a relevant way our theory of perception, which would then be seen as the interface between the internal and the external world.

JENS DEGETT: ***Life has chosen a small number of possibilities, which are consistent throughout the whole of life systems. Every organism goes through the whole evolution and thus is anticipation built in each of them.***

JENS DEGETT suggested an answer to the issue about the extremely high number of possibilities in which life could express itself (how the DNA's genetic codes transfer into proteins) but does not really exploit all of them. If compared to chess, the case is that if everybody in the world played chess all the time they would still never play all possible chess games. It is important to realize that life has only explored a tiny part of its possibilities. Besides, we find that life is extremely coherent, the way how proteins are built up or how chemicals interact is done in exactly the same way. Biology chose one way and all life systems use the same way consistently, the genetic code itself being preserved from the smallest bacteria through the highest life forms, with very few exceptions. Life is so coherent that it has only explored a small pad of the chess board, and this fact helps us see that actually all living organisms are part of the same development, with the same origins, and this by itself gives them anticipatory abilities. This is because every living organism has been through the whole evolution, within its development of proteins and of all its living systems it has actually obtained adaptation and anticipation of what could come in the future. Anticipation has thus been built into all living organisms by evolution.

ROBERTO POLI agreed that anticipation is an evolutionary outcome. But for him the question remains about why such a tiny part of the whole chemical space-state is explored by life. Even assuming that from a chemical viewpoint some combinations are not suitable for life, it still seems that the remaining possibilities are much bigger than what is explicitly exploited by life. This fact raises a question for Roberto Poli: are there some authentically biological constraints (besides the obvious chemical constraints)? His claim is that there should be something else, possibly some type of biological law could be at work in this field, with a constraining effect. Another thing to consider in this context is that life has a tendency to reinvent what it already knows, what is called convergence. When evolution finds a working solution, it tries to repeat that solution time and again (for instance the camera-like eyes appear in evolution many times, even for beings without brain). There is something that is not understood well enough about this situation. Convergence, the repeated invention of the same solution when it works, seems to be some kind of biological property. Intuitively it seems that there could be more biological laws active behind these phenomena, but they have still not been found, being for the moment just a part of the researcher's agenda.

Rufina Gutiérrez: ***A change in language forces us to change perspective. Self-referential systems are open. Structures and systems differ in their type of causality.***

Rufina Gutiérrez first commented on Adolfo Castilla's intervention about language. She admitted that there are many takes on language from the cognitive sciences or even what is called engineering of knowledge. In some cases it seems that they are just inventing words, but the change in words enables us to look at realities in a new way. A change of words makes a difference, because it forces us to change perspective, from a fixed position to a new one. This is good, even if they just say the same with other words or in other language. Thus it is a pity that the last points about the Engineer's answer, and the Biologist's answer were left out of the talk, because their viewpoints would have been complementary. Another point was related to self-referential systems, where language is also important. These systems must surely be open because otherwise autopoiesis would be impossible; but this term 'open' was avoided during Poli's talk, and it is important to say it in order to put things in their real place. About the differences between structure and system, Rufina Gutiérrez pointed out a main difference related to causality: for structures causality is fixed, but for systems we face a dynamic causality.

Roberto Poli agreed about language not being just language but a way of looking at things in different ways. Concerning the Engineer's answer to anticipatory systems, engineers usually look for controllers. They would wonder about which kind of controllers will provide a system with anticipatory capacities. We know at least two types of controllers: feedback controllers (which control the environment) and feed-forward controllers (which control the system itself). The Biologists' answer is even more interesting, because they would say that nothing special is needed, as the capacity of being anticipatory is already contained within the self-referentiality of the system. Poli also agreed that the self-referential system should be open; pointing out that the structure is precisely the closure of the system. Being open and closed for self-referential systems has a slightly different meaning from the general system theory. 'Open' means the same: contact with the environment, but 'closure' means in this case generation of structure: the system develops machinery for reacting or for implementing a specific behaviour or strategy. 'Closure' is the structure the system is able to acquire through its experience.

After these words, Javier Leach closed the session inviting those interested in continuing this discussion to attend the debate that would take place on the following day.

III. DEBATE WITH ROBERTO POLI

After the interesting conference given by Roberto Poli on *Evolution and anticipation*, Sophia-Iberia offered the participants of the seminar's first session a debate with Roberto Poli with the objective of reaching a deeper understanding of the proposed theories and their application to the theme of the seminar: the origin and nature of human reason.

As moderator, Christine Heller indicated that she would employ the «Engineer's answer» – mentioned by Poli in his publications – and seek a role as a (general purpose) controller of the debate (system) in order to advance the knowledge of the seminar.

Javier Monserrat: ***Connect system theory with epistemology and reason.***

Javier Monserrat presented a scheme of his synthesis of the contribution of Poli to the seminar. He formulated numerous questions that are further developed in his contribution to the seminar (see below), and amongst which we can list the following:

- Can we consider anticipatory systems in purely physical realities?
- Can we say that sensation is a new feature or property?
- Can we consider anticipatory systems without memory?
- How does the mind develop or function?
- What system of causes has produced human reason?
- Is human reason a system of analysis/synthesis?

Roberto Poli replied that he was in sympathy with most of what Javier Monserrat presented. He began by commenting on the connections between physics and anticipation, and mentioned that the fact that even the merely physical world presents anticipatory features is being defended by a reduced group of scholars. One of the authors defending this thesis is Daniel Dubois – the organiser of the series of conferences on Chaos – and Juan Ferret has also written on the topic («The Physics of Anticipatory Systems»).

Concerning evolutionary epistemology, Poli is a supporter of this theory, especially as proposed by Donald Campbell who he considers the main figure together with Popper. The two aspects of Campbell that Poli referred to were how he applied Gestalt theory to social phenomena which he believes is an interesting connection. The second aspect that he underlined was Campbell's idea of *downward causation*.

Supposing that the world presented a linear structure: physical, chemical, biological entities, etc., Poli asked which kind of causal connections keep them together? Of course there is causation among physical entities as well as upward causation to the chemical ones. Campbell was the one to ask about feedback. What if higher-order levels of organisation can influence or constrain the lower-levels from which they emerge? If downward causation can be scientifically proved, it makes the whole of reality even more *holistic*. This implies that there are causes working in all the directions. There could be both upward and downward connections, meaning that the various levels are kept together in a very strong manner. Even if it is called evolutionary epistemology, it is a very strong ontological thesis connected to a proper understanding of causation which is one of the basic aspects of reality.

Replying to the questions referring to systems, Roberto Poli sustained that we are still in need of a proper theory of systems as the classic theory – a set of elements and the interactions between them – is no longer sufficient. He illustrated this with the example of the difference between systems that have or do not have the capacity to learn. Systems that are not able to learn, present only one level of internal organisation (i.e. elements and interactions). But a learning system cannot be described as elements and interactions, as they need two levels: a level of interaction and a second level that can modify the interactions between the elements.

If we accept the existence of self-referential systems, which produce the parts of which they are formed, we cannot start with a set of elements as the very elements that form the system are a result of the functioning of the system. Poli believes that the family of systems includes different types: simple classical ones and others which are more sophisticated systems which need to be modelled.

Roberto Poli finalizes by saying that he cannot accept the aspect of epistemology, as he believes that it does not exist and never speaks of it. In his view, knowledge is the behaviour that some systems are able to show; exactly those who have an idea of themselves and their environment in which they behave. Knowledge is a property that some systems are able to develop, but this is an ontological interpretation of knowledge. Poli seeks to see everything from an ontological point of view, as he is interested in reality and the structure of reality. He believes that knowledge is an aspect of reality and a property that some systems have. What he is interested in is finding out how knowledge is possible in a systemic way.

Finally, Poli stated that hyper-complexity (higher-order complexity) is close to his heart and is one of the great advancements of contemporary science. The problem with it is that the internal machinery of complexity theory is purely algorithmic and he asked: can we be sure that all types of complexity are of this form? Considering the complexity of biological entities, there seems to be something more that we should try to understand. That is higher-order types of complexity which do not depend on an algorithmic type of machinery.

Even if there is no theory of hyper-complexity, it is important to raise the question: are we sure that all the complexity we analyse is mechanical? Everything from biology on requires a new theory of complexity, which is less rigid and does not depend on internal mechanical machinery. To Poli, it hints at something more that is needed, and should be developed.

Miguel Lorente: *Possibility to apply system theory to all types of reality.*

Miguel Lorente started by asking if it is possible to use the same ontological system or scheme for the different types of realities: physical objects, structural space-time, mathematical entities, biological systems, human beings and societies. Do they have comparable elements or properties, as the anticipation that has been mentioned by Poli?

Roberto Poli answered that he was always surprised that there was only one world but many different sciences that describe different aspects of it, and this was the only way forward due to the complexity of reality. Each science provides useful information, but Prof. Poli believes that ontology is an effort to build up a general network of categories that working together with the different sciences can provide the glue or connecting links between the different pieces. At present, there is no science of the sciences and there seems to be a need to arrive at a unified or partially unified vision of the world.

This effort, as a philosopher, is to try to extract from the different sciences their categorical grid or network and see where they can be coordinated using even more abstract and higher-order categories. The underlying hidden premise of this approach is to accept that the different disciplines have their own natural ontological inclination. Each discipline tries to model and understand only the phenomena that they are interested in. This strong ontological orientation leads Roberto Poli to view disciplines as pieces of ontology, instead of epistemology. Ontology is the most abstract and general categorical network that can attempt to connect the outcome from the different disciplines. This is a purely Aristotelian point of view and an old-way of looking at things – with a new terminology – by trying to synthesize the various outcomes of each discipline that can often be contradictory and even impossible.

Within this general portrait, a good theory of systems would be the needed framework to help sustain this picture. Finding properties that are valid across the different sciences, such as anticipation if proved, is relevant in presenting a strong vision of reality. There are also a number of new questions that emerge when we try to converge and compare the different sciences that do not appear within each discipline, so that new research paths arise.

The moderator underlined that to be able to ask these new questions it is necessary to learn the new languages associated to each discipline, as they can be one of the main obstacles to interdisciplinary and transdisciplinary research.

JAVIER LEACH: *Structures and systems. Computable functions related to ontology and categories.*

JAVIER LEACH: pointed out that a system is a set of open structures, but the way we understand an open structure is also in a structured way. An open structure is an element of a greater structure. An example of this is that when we prove that a function is non-computable, this is done with a computable proof. When we speak of systems we can interpret this as a *structure of structures* where not all is computable and therefore it is an open structure.

This is related to how we understand the world. There is an algorithmic way but also by means of perception, when we accept a structure it is because we have perceived the structure but we do this differently in each discipline and we accept the structures. The problem is to put into connection the different structures within an open structure.

Perhaps the creation of a general network of categories – which Poli calls ontology – could be considered as logic, as a way of structuring our knowledge?

ROBERTO POLI replied that it is important to distinguish the world from the tools. Mathematics and logic are tools that are essential for science, but one should not confuse the map with the territory. Some of the models are better than others and most of the disciplines are incomplete and it can be accepted that even our best ontological interpretation of reality might remain incomplete, even if we try to go as far as possible with the tools we have.

Perception is an interface between a system and its environment. Each system may perceive the environment in a different way – such as humans and dogs, which do not see colours – as there are different ways of obtaining information. There are different types of perception and interfaces – without being relativistic – because as soon as we know how the perceiving apparatus works we know how the system sees the environment. This is objective and it is the measuring device that categorizes the environment in different ways.

Even if we depend on partial tools – eyes, ears, … – if we know how they work we know the objective information that we can extract from them, and we can understand what is going on between the two systems (leaving quantum mechanics aside).

CHRISTINE HELLER: *Mathematics as a language not a tool. Language considered as a tool for cognitive processes of the mind.*

CHRISTINE HELLER indicated that natural language is important for perception and is related to the cognitive capacity of human reason which determines the conclusions that are reached, in the same way that mathematics is the language necessary to develop models that are used to predict certain phenomena in engineering.

ROBERTO POLI responded that calculations cannot be done with natural language that is used for communication, whereas, formal languages are used for calculations and for developing models. Why do we say that «the glass is on the table» and not «the table is under the glass»? It is difficult to understand why natural languages work in a specific way and they seem to have hidden constraints.

Christine Heller replicated that humans develop their mental models using natural language and it therefore seems to be a very important tool for reason.

Roberto Poli retorted that formal languages require a set of meta-languages and in the case of natural language; meta-language is within the language itself which makes it more flexible.

Christine Heller disagreed, but the debate continued.

Rufina Gutiérrez: *Reactive systems are not anticipatory and it is not possible to artificially reproduce common sense.*

Rufina Gutiérrez pointed out that the word 'anticipatory' is being used as a big umbrella for almost everything. In Ferret's terms: «all conservative systems are anticipatory». Prof. Poli had also talked the prior day about 'memories' even in non-living systems, but obviously it is not the same kind of memory that human beings have. She stated that a wider definition of memory is required. About the case of the roots of trees which look for more territory, she thinks that this is just a reactive system like in the case of the amoeba, and these 'reactive' systems are very different from the 'reflective' ones, which are able to build a model of the future, in a way that can affect the present. But most biological systems have a non-representative type of anticipation. She said that all Poli's discourse could be put in these three categories in her mind (conservative, reactive, reflective) and asked the professor if it would be acceptable for him to classify all systems into these three categories.

Roberto Poli replied saying that he does not assume that reactive systems are living nor anticipatory, and would like to clearly distinguish between these two cases: the reactive systems simply answer to what happens, while the anticipatory systems take decisions before something happens.

Rufina Gutiérrez then quoted a sentence from the Preparatory Document: «evolutionary survival implies that all living systems are characterized by some form of strong anticipation, while some of the most evolved species may enjoy weak [cognitive] types of anticipation as well» (R. Poli, *An Introduction to the Ontology of Anticipation*).

Roberto Poli defended that for most theorists of evolution it has been typical to claim some kind of anticipation for living systems, but only recently some new possibilities are taken into account for the study of the whole phenomenon of anticipation. For reactive systems we could use now other categories as 'feedback' or 'feed-forward controllers'. He explained how the quoted sentence should be understood, and then showed himself completely in agreement with Rufina's idea that 'reactive' is not 'anticipatory'.

Rufina Gutiérrez further explained that in her own field she studies learning difficulties, epistemological and then ontological barriers for learning. We can use models with computational tools and build artificial intelligent systems, but in her opinion it is impossible to build an effective model that reproduces common sense.

Roberto Poli said that we have technologies for sending ships to the moon, but not for making a mixed salad. Technology is useless to replicate processes that don't have an algorithm.

Manuel Béjar: *Is life different from intelligence? If not, what has produced life?*

Manuel Béjar began his comment stating that there are three main questions to ask in order to understand reality: What is matter? What is life? What is reason/consciousness? The ontology of matter has two different activities: physic and psychic. If we would consider that plants can have intelligent activities, then what would be the difference between 'life' and 'intelligence'?

ROBERTO POLI replied that all forms of life have some kind of intelligence; it is part of their struggle for survival. A complete idiotic way of life does not exist. In Poli's opinion intelligence is coextensive with life. But, of course, he admits that there are different types of intelligence. It is an umbrella term that requires further distinction of types. All forms of life would have some kind of perception or psychological behaviour. He suggested the possibility to explain reality asking 4 questions: about matter, life (intelligence), mind and society. Then he pointed out that there also are different types of minds and societies, probably interrelated, like some kind of minds would only be present with some kind of intelligence and some kind of society.

MANUEL BÉJAR then asked if the same categorical framework can be used to understand these three concepts. That is, if one can join mind to biology or mind to living systems as well as the different levels of mind and consciousness.

ROBERTO POLI did not agree. He defended that the categories, the framework that explain biology are different that the ones needed to explain mind. All minds we know are embedded in organisms, they require brains, but explaining an organism requires different categories: it can be measured and weighed, but ideas or perceptions do not have length or weight. Both of those realities are connected, but are also autonomous, and that means they need different categories, although they are usually confused. Cognitive studies are not the same conceptually as brain studies.

MANUEL BÉJAR claimed that there is a big gap between matter and life, so that we can say very clearly that some kind of matter has no life. But it is not so clear when speaking of intelligence and biological entities, if we can only say these entities are more intelligent than those ones. In this situation he preferred to ask Prof. Poli: what has produced life?

ROBERTO POLI answered that science does not know yet exactly the processes of how life started or mind emerged, but we know their products. So we should start by describing the various types of entities as faithfully as possible, and then discover the connections, what came first and what came later. Then one could be lucky enough to develop models.

ADOLFO CASTILLA: *Which is the role of ontology? Is anticipation an emerging faculty?*

ADOLFO CASTILLA asked for the role of ontology, as this discipline is not scientific at all. For him it is interesting to approach the 'cognitive' question from the point of view of neuroscientists and neurophilosophers.

ROBERTO POLI replied that he respects the position of those who deny that ontology is necessary. But in his opinion many scientists defend that there is a need for something like that, in order to put together all those different kinds of realities. As a matter of fact, he has found out that the worst enemies of his perspective are mostly philosophers, because main-stream philosophers nowadays have lost the sense of ontology. The problem would come from Kant's «Critique of Pure Reason», because the philosopher, for the second edition of this book, left a few paragraphs out, with the effect that categories assumed a different nature. Philosophers that keep the great sense of ontology prefer the first edition, but Neo-Kantianism evolved so that main-stream philosophy tended to forget about ontology, although this discipline could seem to be now slowly trying to recover. Unfortunately, two of the greatest philosophers of the 20th century, Heidegger and Wittgenstein, developed an ascientific version of philosophy. So that today the problem in the interdisciplinar dialogue does not usually come from scientists, who are generally interested in their own fields and even some of them develop an interest for philosophy. Philosophers are the ones who should try to develop ontology anew.

ADOLFO CASTILLA asked then if Prof. Poli would say that the anticipatory faculty of a system is an emerging faculty.

ROBERTO POLI deemed necessary to clarify if the question was implying that some living systems are and some are not anticipatory, or if it was just asking whether this characteristic emerges with life. His honest answer was that he does not know, but, as said before, he considers anticipation coextensive with life and stated that this perspective is fairly recent.

JOÂO CARLOS PINTO: *What kind of definition do we have for 'intelligence'?*

JOÂO CARLOS PINTO wondered what kind of definition we should use for 'intelligence'. Should it be an ontological, accidental, qualitative or quantitative difference or something else?

ROBERTO POLI indicated two aspects of this issue. In first place, considering intelligence for different types of living entities, he suggested we should start with the simplest way to understand intelligence: as problem-solving. But this approach is not appropriate for all types of intelligence. As it is not the same to be able to calculate or to have the ability to solve everyday problems (common sense). For life, this second type is the most important. When intelligence is measured by tests the results are dependent upon culture, because people from different cultures develop different types of intelligence. In our task we should begin with the lowest possible point: the ability of problem-solving.

Moderator Christine Heller ended the session and invited the participants to continue the debate during dinner, in a nearby restaurant, reminding everybody to use their common sense – that seems to be the least common of them all – as anticipatory system to beware about the dangers of crossing the street.

IV. CONTRIBUTIONS

JAVIER MONSERRAT: *How to explain reason in terms of systems theory.*

Roberto Poli posed the question: what is life? His response is built from the conceptual framework of systems theory. He attaches particular value to the fact that life is shown as a system a) autopoietic b) anticipative, c) unitary, total, holistic (whole), d) where organization is determinant and preferent, if we compare it to the pure content. However, living as a system is to live within the structural dynamics (systemic) of the world. This implies that the living being, in order to survive in a structural environment, should «represent» the world as a system. Therefore, the evolutionary higher stage of this representative capacity of systems (structures) is identified with human reason.

In this sense, the theory of systems (structures) a) could help to describe the nature and operation of human reason as «representative process for analysis and synthesis of systems (structures)»; b) the evolutionary process leading to emergence of reason could be understood in terms of the formation of successive mechanisms of increasingly complex systems analysis. Action toward survival (response) would then depend on a prior «systems analysis» (systems representation).

Therefore to consider the evolutionary origin of reason in terms of systems theory involves reconstructing the various stages in the evolution through which the analysis of representative systems in living organisms have been emerging. We can suggest some features of these different evolutionary stages.

The crucial question is: when does it appear in a real system a «model» or «anticipative model» of its environment? What we want to say is related to this, if we consider that a system contains a «representative model» of the environment. Human reason could hypothetically be the result of an evolution (from the most simple to the complex) in systems of environmental representation based on the analysis and synthesis of systems.

1) Ontology of reality. The universe is made of interconnected structures that form complex systems (system = organization of structures). A mass of iron material is formed by iron atoms linked together: the resulting reality is a complex network of structures and systems immersed in each other. The elements of the structures (or systems) are linked together by «relationships», «forces» (the four forces of nature) or «operators». The ontology of reality has been produced by the intrinsic properties of matter that result in the so-called laws of nature.

2a) Purely physical realities: natural. The universe is dynamic. The immense energy produced in the Big Bang has created a cosmic dynamic in which matter is organized and disorganized by forces of blind action and reaction. Physical entities are structures and systems (these two concepts should be defined in scientific use) that do not have autopoiesis, but they represent a whole with organization. Are natural physical systems also anticipative? It's hard to admit it, but all natural physical systems contain information on how the world is (the matter and its laws) and, therefore, it involves (at least in certain time intervals) a certain blind expectation about the future (biology of knowledge, evolutionary epistemology: Rupert Riedl, Konrad Lorenz).

2b) Purely physical realities: artificial. We are speaking about engineering of anticipatory systems. It has been made possible to design and produce machines with self-control (cybernetics). These physical entities have a cybernetic model of the value of system variables and self-regulation (feedback). They are physical systems with an anticipative model, however they are not natural but designed by human intelligence.

Let us consider now a few moments in the emergence and evolution of life:

3) Stage of pre-living purely physical and mechanical entities. We must assume that life began through a previous purely physical-mechanical cellular stage. Probably something similar to the virus (are viruses living?). These biotic systems (or prebiotics) could be understood: a) as physical systems of purely physical action/reaction, b) as a true natural-looking engineering design (cybernetics). In the previous stadium of evolution life could have designed the first purely physical natural cybernetic systems. These systems a) are a whole, b) do have organization, c) do already have autopoiesis. But are they also

anticipatory? In my opinion, if we admit that life was primarily a purely physical natural cybernetic system, then we should also admit that life was in its beginning a natural design of engineering cybernetics.

4) First stage: mechanical-sensitive living entities (Amoeba, Paramecium). Life began to organize itself as a blind, mechanical and cybernetic system. However, it seems that we must admit that at a certain point of the evolutionary process (probably in the single cell level), emerged «sensation». The pre-existent mechanistic processes were coordinated with sensation. This new system provided the optimal tool to detect the state of the internal and external environment (information system). There was then an emergent learning connection between stimulus (sensation) and response (motor mechanisms). This primordial learning is to be understood already as a primitive form of memory based on sensation (not just mechanical). The living entities in this stage a) are a whole, b) have organization, c) with autopoiesis, and d) anticipation by a memory system based on mechanical-sensitive processes. In addition, they are systems that work through the stimulus/response that should be understood as an automatic and deterministic connection (let us say that these entities are only «sensitive automata»). What the evolutionary psychology (and neuroscience) will call a «psychic subject» has not still emerged in these systems.

The operation of these «sensitive automata» – as primitive single-cell systems – could be explained by the model of an «initial semiotic system» (such as the semiotics of Charles Peirce). There is here a «systems analysis» (connections between sensations and mechanical responses). These connections are recorded in some way, so as to facilitate the recognition and the responses (memory). Then a new biological memory emerges that is «mechanical-sensitive» (not only mechanical). This «semiotic analysis of systems» based on a primitive memory (similar to learning) could be the basis for the discussion of anticipative behavior (registered in the memory of «systems of connections»). Implication: we may understand that evolution has chosen the line to survive in a «world of systems» based on a «systems analysis» through a certain primitive biological proto-memory.

5) Second stage: Pluricellular organisms (chameleon). Semiotic systems would be similar to unicellulars, but more complex. They would be: a) a system, b) with organization, c) with autopoiesis, and d) with anticipative systems. These new «organisms» (with organic systems) would be «sensitive robots», but the amphibian (chameleon) have already established a primitive «psychic subject»: their body feels and reacts as a whole connected with automatic coordinated responses. The chameleon (amphibious) has already organic systems, for example, the visual system (reacting to «visual images», as the fly hunting guided by vision).

The emerging cognitive system is a more complex one. It could be understood in terms of a new «complex semiotic system». These living organisms would contain: a) an analysis of systems (connections from images produced by a more complex new system of senses, such as vision), b) possibilities to record in memory through more complex neural mechanisms, and c) means to act accordingly as anticipative systems (expectations about the future based on the memory of connections). At this stage, therefore, evolution would have succeeded in changing the design of a more perfect adaptation to the environment through improving the «mechanisms for the analysis of semiotic systems».

6) Third stage: superior animals (apes, dogs). Everything works as in the previous stage but with greater complexity. a) Memory has been refined by the action of the temporal lobes of the brain. Brain images of the past are going to be activated in the animal mind, in coordination with the images in real time. b) The «psychic subject» is more complex and it has already a «memory of itself as an active subject». c) The psychic hyper-complexity (on signs and on automatic response programs) has reduced the force of the automatic responses and it has started to form a more complex system of response mechanisms.

In this new stadium, a new cognitive system emerged (in continuity with previous semiotic systems). The previous semiotic system can now be called a «signitive-instintive behavior system». It is based on a complex memory that can be understood according to Gerald Edelman's theory (the remembered present). The mind begins to function as an «images combinatory» that connects past with present (Edelman). This allows a series of new protohuman psychic activities: representation, categorization, abstraction, imagination and the early elementary logic functions. We can then speak of «protohuman cognitive processes». These processes, based on memory, give the animal the capacity for a) a more complex analysis of connections (systems analysis) and b) a more complex model of the future ahead, or let us say, a more complex anticipative behaviour.

7) Transition between third and fourth stage: the origin of human reason. Today it seems common in ethology literature to speak of «protohuman behavior» in superior animals. It is therefore correct to speak of the «protohuman emergency of reason» in these animals. Related to this are some key issues: a) What are the differences with the animal world and what new features appear in human reason? b) How to define precisely the nature of human reason? c) What system of causes have produced the evolutionary transition from «protohuman reason» to «human reason»? [Presumably, the knowledge of the «causes» of the «evolutionary transit» to human reason will help us to know the differences with the protohuman animal reason and also to know the nature of human reason].

Therefore, the crucial question points to the causes that led to the evolutionary transition to human reason from the minds of superior animals. In this connection a number of authors and schools have suggested some systems of defined causes. In our opinion all these theories should be known, discussed and evaluated. We note the following theories and proposals: 1) Unspecialization theory (A. Gehlen): 2) Hominization by labor (Marxism), 3) Hominization by socialization/language (Eccles, Tobias, Leakey); 4) Hominization by protohuman evolution of behaviour and cognition (Lorenz, Riedel), 5) Hominization by neural hyper-formalization (Zubiri), 6) Proposals of Charles Peirce; 7) Proposals of Whitehead; 8) Results of human evolution in the scientific perspective of palaeoanthropology.

8) Fourth stage: human reason, human mind. That is the question that we have still open. It can be answered from the perspective of systems analysis (after

the different stages in evolution of animal minds can be understood in terms of progress on the complexity of responses based on a preliminary analysis of systems). In continuity with the systems theory, our proposal is that the human mind should be understood in terms of a) a hypercomplexity emerging in systems analysis and b) in terms of the emergence of the capacity of hypercomplex anticipation.

JAVIER LEACH: *Systems Theory (ST) as an open formal ontology.*

I agree with Roberto Poli that the most obvious characteristic of human mind is represented by language and its capacity to organize things. I agree also that the unitary character of ST expresses the unitary capacity of the human mind. ST is a meta-theory establishing meta-relations between systems. Can ST express all capabilities of human language? Could we say that ability to analyse reality as a system exhausts human intelligence?

My comment is on the capabilities of ST and its openness.

Among the systems studied by ST we can distinguish the *real* and *formal systems*.

1. *Formal systems*

Formal systems are characterized by their formal syntax and especially by their formal semantics. In formal syntax the well-formed formulas are recursively defined from an *alphabet*. An alphabet consists of *logical signs*, *variables*, and a *signature,* which is specific for each theory. Formal systems are apt to be treated by computing machines.

For example, the First Order Logic (FOL) is a formal system whose alphabet consists of the *logical signs* such as ∀, ∃, ¬, ∧, ∨, =; *variables* such as x1, x2, x3, …; and a set of signs called *signature* for each specific theory. For example a signature for arithmetic is: $\Sigma_{ar} = \{0, 1 +, *, <\}$.

Model Theory, which has its origin in Alfred Tarski (1902-1983), is the more usual semantics for formal systems. Model Theory defines recursively the truth or falsity of the formal statements in a formal mathematical domain of interpretation. There are other semantic alternatives to Model Theory such as the Truth-value semantics, Games, Kripke, Proof-theoretic semantics…

2. *Real systems*

The main difference between formal and real systems consists in the semantic meaning of the *signatures*, otherwise the logical structure and the variables of the real systems can be formalized. The substantial difference consists in the fact that formal signatures can be semantically interpreted in formal models whereas the signatures of real systems are necessarily interpreted in real models representing facts and observations. To emphasize the difference between formal and real signatures, I will call *formal signs* to the elements of formal signatures and *representative signs* to the elements of real signatures.

For example, the words mass, energy and heat are representative signs. They represent properties of real physical observable objects. In a similar way the words adenine and thymine are biochemical representative signs, representing real objects observed in the DNA. On the contrary 0, 1 +, *, < are formal signs.

3. *Open systems*

A system is open if it has properties that cannot be deduced from other more basic properties.

Formal systems are open. The incompleteness and undecidability theorems show that sufficiently complex formal systems are necessarily open.

Real systems are also frequently open. The real systems of quantum physics, biology and neuroscience are open systems, because they have emergent properties that cannot be deduced in a logical-deductive basis from other more basic properties.

In an open formal system we can add as an axiom a property that cannot be deduced.

In the real systems the emergent properties can be also added to the system on an observational basis.

4. *Explanation of real systems by means of formal systems*

The formal, precise and accurate explanation of real systems by formal systems allows scientific prediction and technological applications. This implies that the formal explanation of a real system by means of a formal system adds real meaning to the formal system.

For instance, technological applications and predictions of the theory of relativity are based on their mathematical formal explanations of the relativity theory.

5. *ST is a formal and open meta-system*

ST is a meta-theory that seeks to describe relations between systems, real and formal. While particular systems may be formal or real, the meta-relations that ST studies are formal.

For example, autopoiesis and anticipation are representative signs meaning a special kind of real relation within and between living real systems.

But autopoiesis and anticipation can also be studied as formal relations in an open formal system; in fact we can simulate autopoietical and anticipatory behaviour in computing programs.

Being ST a meta-theory of open systems, it is necessarily an open system because there will always be properties that we cannot deduce in a logical-deductive basis.

Conclusion

ST is by its general nature a general ontology that unifies the various scientific disciplines. Furthermore, by its formal nature ST is commonly used as a formal ontology in computer science. However, due to its openness, ST opens the way to the kind of basic metaphysical questions about the origin of reality in general and in particular of the origin of human mind. And in the case of the origin of human mind it raises in all its starkness the question of the relation between formal systems and reality.

V. PRELIMINARY CONCLUSIONS OF SESSION I

Roberto Poli has pointed to the theory of systems, especially to anticipatory systems, in understanding the nature of life. This has given us the occasion to attempt to explain the nature of reason in connection with the theory of systems. It seems in general to be thought that the origin and nature of reason has to do with the fact that the universe is a structure (or system of structures). Life, and therefore reason, should be read in conjunction with the idea of «structure» (or «system») and, as a consequence, in relation to the formal sciences in general. Not only with the theory of systems. It will probably be necessary to reflect further on the concept of structure, system dynamics and structures and systems (in complementary and interdisciplinary connection with various formal sciences).

Life has been, in effect, the origin of the evolutionary process leading to the emergence of reason. In relation to the concept of life proposed by Poli (a whole, with organization, autopoiesis and anticipative system) it is questionable whether to add or not other features, for example, «sensation». Can we talk about life in purely mechanical systems, which are not «sensitive», for example in systems such as viruses or only physical-mechanical primordial cells (but having an anticipatory system acting as cybernetic self-control)? An artificial cybernetic system (engineering) with complex anticipatory systems, could be considered «life»?

Related to this, we should not forget the so called today computational theories of man (they imply a consequent computational understanding of the nature of life). Computational theories can be either serial (Newell, Simon) or connectionist, parallel distributing processing PDP (McLelland, Rummelhard). Neither of the theories has been discussed here, during the presentation of Poli nor in the discussion of this first session.

Understanding reason is likely to require further reflection on the concept of memory through various evolutionary stages. We can speak of memory in mechanical systems (e.g. in engineering cybernetics). Can we speak of memory in prebiotic systems? What is the role of «sensations» or «memory images» in the emergence of reason? How are coordinated «mechanical memory» and «images memory» in the functioning of knowledge in animal mind and human reason?

The mechanisms that explain the semiotic systems of primitive response to the environment can be understood in terms of analysis of structures (or systems)? Do superior animals have protohuman functions? What do we think scientifically about the «system of causes» that has produced the evolutionary transition from animal to human mind (reason)? Can we explain this transition in terms of systems analysis and synthesis?

The crucial question that has been raised in this session is: how to understand human reason, its evolutionary origin and functional adaptive nature in terms of the concepts of «structure» and «system»?

VI. ADDENDA OF SESSION

Miguel Lorente Páramo: ***Space-time ontology.***

I want to present my reaction to the «Ontology and evolutive genesis of reason». Therefore I will try to connect my comments with my last papers on the ontology of space-time.

1. The ontology of scientific models

The type of reality depends on the epistemology somebody is defending: i) A logical positivistic philosopher will defend that the mathematical and physical model are nothing more that formal schemes. ii) A realistic philosopher would try to convince us that our scientific models reflect the reality on itself. iii) And an evolutionary will present the first principle of being changing in time.

We apply this scheme to the problem of life. We first review the ontology of cosmic beings and their ontology and evolution and finally will apply the ontology of mathematics.

2. The one and the multiple

According to Teilhard de Chardin, the structure of cosmic beings is based in the duality «one-multiple» consisting of the self realization of one being of higher perfection in other beings of lower perfection. The causal relation between the being of higher and lower level has an intrinsic character (formal and material causality). By the contrary, the causal relation among beings of the same level is of extrinsic character (efficients causality) The existence of each cosmic being is realized by the mutual communication of the one in the multiple through the immanent principle (the principle of being-in-himself). The interaction of one cosmic being with others of the same level is fulfilled through the transient principle (the principle of being in others).

According to this scheme the evolution of a system runs as follows: first, the set of all elementary beings was created. This creation gave rise to the existence of space-time. Using the mechanism of Teilhard we could explain the appearance of beings of higher perfection: space-time, elementary particles, atoms, chemical compounds, biological entities, vegetables, animals, human beings. Some of the comments have been concentrated in the transition from the physical entities to living beings, but the mechanism can be extrapolated, the first stage of the evolutionbook.pdf

Ref: «An ontological Model of Matter and of Space-time» (Abstract on-line, pp. 107-108: http://www.upcomillas.es/Sophiaiberia/doc/Conference%20 book.pdf).

Parameters of evolution and their degrees

In the description of evolutionary steps play an important role the so called parameters of evolution. This expression has been proposed by the biologist and theologian Karl Schmitz-Moormann in his book «Theology of Creation in an Evolutionary World» (Pilgrim Press, 1997). The parameters are:

1) Union, responsible of the creation of the new being, after the process of complexification took place
2) Conscience, that faculty for the communication with the external world that results in the creation of the living being.
3) Information, that is received from outside in order to make decisions in favor of the living being.
4) Freedom to make decisions, needed for the adaptation to the external world.

In my opinion there is a lack in the exposition of these parameters, and it is the degree in which each parameter can be measured. This type of measurement was developed by Teilhard de Chardin, when he claimed that every quality (parameter) that was present in the human being could be found in other beings of lower perfection but in a lower degree. He gave the example of the conscience in human beings, as well as in animals, plants and inorganic materials.

Ref: MIGUEL LORENTE, «Karl Schmitz-Moormann une la teoría evolutiva con la teología de la creación» (online: http://www.tendencias21.net/Karl-Schmitz-Moormann-une-la-teoria-evolutiva-con-la-teologia-de-la-creacion_a3430.html)

3. AN ONTOLOGICAL MODEL FOR THE STRUCTURE OF SPACE-TIME

Nothing prevents us to apply this scheme (the one and the multiple) to the first evolutionary layer of the cosmos. From this layer of fundamental entities that we call «hylions», emerges the elementary particles, and other beings of higher perfection.

The model can be described by graph theory and it is relational, because we have only objects interacting among themselves, which can be represented by vertices and arrows: there must be an isomorphism between the elements of the graph and the fundamental objects of the system.

Ref: MIGUEL LORENTE, «More on Discrete Spacetime» (on-line: http://www.Newton.ac.uk/programmes/DIS/seminars/032616306.html)

I received the following comment from Prof. Poli:

> «I have read your powerpoint presentation of discrete spacetime. As you can imagine, my interests are closer to its first part than to the subsequent developments. I perfectly agree with you (and Zubiri) that potentialities should play a mayor role in our vision of the world. If we accept the idea that the world is a dynamically unfolding reality, then our theories should have room for potentialities or – as I prefer to say – "latents"».