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An Introduction to the Ontology of Anticipation

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1. Introduction

Recent years have witnessed the growth of significant interest in theories and methodologies which seek to foresee the future development of relevant situations. Studies of the future fall under many different denominations, and they employ a huge variety of techniques, ranging from forecasting to simulation, from planning to trend extrapolation, from future studies and scenarios to anticipatory systems. Widely different conceptualisations and formalisations have been proposed as well.[1] This remarkable variety may be partly simplified by making explicit the main underlying assumptions of at least some of them. Two of these assumptions are that (1) the future is at least partly governed by the past, and (2) the future can be better confronted by opening our minds and learning to consider different viewpoints.

According to (1) the future is part of a structured story whose past and present are at least partially known. The claim is defended that the forces that have shaped past and present situations will still be valid while the situation under consideration unfolds. The core thesis is that the future is embedded in the past; it is the projection of the past through the present. Time series analysis, trend extrapolation, and forecasting pertain to this family. Any of the mentioned methodologies may be further supplemented by computer-based simulations.

On the other hand, instead of directly addressing the problem of searching for the seeds of the future in the past, (2) considers the different problem of preparing for the unforeseeable novelties awaiting us in the future. Learning about widely different outcomes is now the issue: one must be ready to consider and address possibly unfamiliar or alien scenarios. The main outcome of this exercise is an increased capacity to distinguish among possible, probable, and preferred future scenarios. These activities come under the heading of future studies, while scenario construction is the best known methodology adopted by practitioners.

For now on I shall refer to (1) and (2) as respectively the *forecasting* and the *scenario* viewpoints. Forecasts and scenarios are not contradictory one to the other. They may and usually do coexist, since they address the future from two different standpoints. Furthermore, experience shows that both are useful.

This paper introduces a third, different viewpoint, here termed the viewpoint of anticipatory systems, which can be profitably synthesized with forecasts and scenarios; i.e. it is not contradictory with the claims of either the forecasting or scenario viewpoint.

Recent years have witnessed the growth of significant interest in anticipation.[2] Anticipatory theories have been proposed in fields as different as physics, biology, physiology, neurobiology, psychology, sociology, economy, political science, computer science and philosophy. Unfortunately, no systematic comparison among the different viewpoints has so far been developed. It is therefore fair to claim that currently no *general* theory of anticipation is available.

Generally speaking, anticipation concerns the capacity exhibited by some systems to tune their behaviour according to a model of the future evolution of the environment in which they are embedded. Generally speaking, the thesis is defended that “An anticipatory system is a system containing a predictive model of itself and/or its enviroment, which allows it to change state at an instant in accord with the model’s predictions pertaining to a later instant” (Rosen [19: 341]).

The main difference between forecasting and scenarios on the one hand, and anticipation on the

[1] See, among many others, Adam [1], Bell [4], Cornish [5], Godet [7], Lindgren and Bandhold [8], Retzbach [16], Slaughter [22], Woodgate and Pethrick [23].

[2] Starting from the seminal Rosen [19]. See also [20], [21].

other, is that the latter is a property of the system, intrinsic to its functioning, while the former are cognitive strategies that a system A develops in order to understand the future of some other system B (of which A may or may not be a component element).

2. Two families of models

To understand the intricacies of anticipatory systems better, it is helpful to start by analyzing the main hidden assumpion of Newtonian models. Indeed, “all the languages so far used to construct models have their roots in the mechanics of Newton” (Rosen [17]). This apparently bold claim can be explained by specifying the information needed to construct a (Newtonian) model. In so doing, one can see that all (Newtonian) models require the specification of two different types of information:

- The *instantaneous state* of the system, i.e. what the system is like at any instant of time;
- The way in which the system *changes* state, i.e. how the system moves from present or past states to new states as a consequence of the forces acting on the system.

In short, instantaneous states involve the specification of state variables, while system changes involve specification of the system’s equations of motion.

For the purposes of this paper, it is worth stressing that all Newtonian models share the basic assumption that the dynamics of the system depends crucially on present and past states of the system. No future information is ever allowed to play any role whatever. Let us state this explicitly.

Main assumption of Newtonian systems: *Never allow future states of the system to affect the present changes of state*.

Physics only considers present states and present forces. On the other hand biological, psychological and social systems need to include also past states (memory) and often past forces. This is a first major difference between physical (or non-living) and non-physical (or living) systems. However, the inclusion of memory, however relevant it may be, is still not sufficient for precise distinction between non-living and living systems. Memory-based systems are still Newtonian, i.e. mechanical, systems, while living systems seem to require something more.

What is required is to add a second and deeper feature, namely future states. I shall call systems that include past, present and futures states *anticipatory systems*. As before, I explicitly state the main assumption of governing anticipatory systems thus

Main assumption of Anticipatory systems: *Future states may determine present changes of state.*

As to be expected, the logic of Anticipatory systems differs greatly from the logic of Newtonian systems. Here I shall rely on Rosen’s definition (see above section 1). As far as I can tell, Rosen has been able to go deeper than anybody else into the intricacies of the model required and supported by anticipatory systems.

3. A model of anticipatory systems

Let me 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 I have to assume 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.

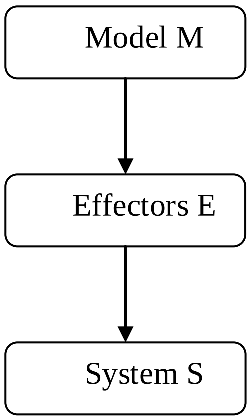
The real novelty arises when we assume that M and S can interact with each other, i.e. that M may affect S and S may affect M.

The direction from S to M can be seen as an updating or an improving of M. This direction is rather straightforward and I shall omit its analysis. 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 hypersimplified way (e.g., without considering either the environment or the upgrading of M) the logical connections between S, M and E.

Figure 1.



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" [17].

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.

Rosen [17] notes that "from this simple picture, a variety of insights into the nature of 'planning', 'management', 'policies', etc., can be extracted". To see them, the whole framework must be decomposed into its main aspects. They can be labelled with the tasks of

- Selecting the model M
- Selecting the control variables in S
- Designing the effector system
- Programming the effector system
- Distinguishing desirable from undesirable regions
- Including a device to reset the model

This decomposition yields better understanding the model, and it enables systematic analysis of the ways in which it can go wrong. Understanding the types of the framework's failures may be of help in devising a methodology to understand the behavior of anticipatory systems.

Anticipatory systems can go wrong in three main ways, which will be summarized under the three headings of

- Bad models
- Bad effectors
- Side effects

Although the first two are rather well known, a short summary of their main sub-cases is worth considering. A model can be bad for

- technical reasons (ignoring relevant state variables, wrong specification of the equations of motion);
- selection of an incorrect paradigm (modeling anticipatory behaviour by means of non-anticipatory models);
- wrong correspondence between the states of system S and the states of the model M.

Effectors can be bad because they

- may be unable to steer S;
- may fail to manipulate the variables of S appropriately;
- may be badly programmed

As said, these cases are well-known. On the other hand the third family – the one called 'side-effects' – is much more interesting. The main result obtained by studying anticipatory systems is that side effects depend on *inherent* properties of the framework. Side effects arise even if the model M is perfect and the effectors E are perfectly designed and programmed. Even if everything is perfect, there will always be side-effects or unintended consequences.

4. Side effects

Side effects (or unintended consequences) are a structural feature of anticipatory systems. By default, when the system S carries out a particular activity A, S uses only some of its internal resources. Technically speaking, S uses only some of its degrees of freedom.

More intuitively, organizations (systems) are such that in their case the same internal structure is usually involved simultaneously in many different functional activities.[3]

Side effects are due to the tension between the fact that (1) the equations of motion of a system S link together all the variables defining S, while (2) the variables not involved in a particular functional activity are free to interact with other systems in a non-functional (even dysfunctional) way (Rosen [17]). As a consequence, all the functional activities of a system S are prone to be modified or lost over time.

Interestingly, given a system S, any functional activity A of S can be modelled by a model simpler than the model of S. The reason is obvious: the model of A does not include all the variables of S but only those relevant to the activity A.[4]

[3] On the other hand it is also true that the same functional activity can be realized by different kinds of structures.
[4] "Indeed, it is largely because of this property that science is possible at all" (Rosen 1972).

On the other hand, no model whatsoever has the capacity to fully capture the potentialities of a system S for interactions with arbitrary systems, because any interaction is specific (i.e., a functional activity). Except for simple systems, no model can represent all the system's relevant properties and/or interactions with other systems (Rosen [19]).
The consequence is significant: authentically complex systems can be understood only on the basis of a number of (interacting) models.[5] Which means that sooner or later all the models of an authentically complex system diverge.
A major consequence of the theory is that effectors E will in general have effects on a system S other than those which are planned (Rosen [17]).
Side effects are a general property of anticipatory systems and there is no general way to prevent them. However, for specific subtypes of the general framework there are ways to address the problem. Consider for instance planning systems. Even if side effects are in general unpredictable, the ways in which a planning system can "go wrong will lead to a particular kind of syndrome in the total system… It should therefore be possible to develop a diagnostic to 'trouble-shoot' a system of this kind, by mimicking the procedures used in neurology and psychology". "It is amusing to think that such planning systems are capable of exhibiting syndromes (e.g. of "neurosis") very much like (and indeed analogous to) those manifested by individual organisms" [17].

5. Types of anticipation

The definition of anticipation provided in section 1 is only a preliminary one to be subsequently refined and improved. As a matter of fact, the above definition and its unfolding in sections 2-4 above considers only *one* single type of anticipation, namely model-based anticipation. Models are forms of explicit, representational knowledge. The next step is to verify whether there also are implicit forms of anticipation.

By considering both cases, one may claim that anticipation comes in different guises. Using the terminology by now adopted by most of the literature on anticipation, it will be claimed that the simplest articulation of types of anticipation is between strong and weak types, where the former (the strong one) is conceived as a coupling between the system and its environment, while the latter (the weak one) is understood in the form of a (cognitive) model developed by the anticipatory system itself (Dubois [6]). As a straightforward consequence, 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 types of anticipation as well.

While the said distinction between strong and weak anticipations makes perfect sense, I am uneasy with the reasons adduced to support it. To my understanding, both types of anticipation are model-based in the way shortly discussed in sections 2-4 above. If so, the difference between strong and weak anticipation shouldn't be based on the difference between having, as opposed to not having, internal models, because all anticipations are based on internal models.

Their difference needs something else. My proposal is to rely on the difference between explicit and implicit models, i.e. on models the systems is aware of as opposed to the case of models the system is not aware of. Providing I am right, anticipation can therefore work below the threshold of consciousness, or it may emerge into conscious purposiveness. In the latter form it constitutes the distinctive quality of causation within the psychological and the social realms. On the other hand, biological systems are better characterized by non-representative types of anticipation.

In either case, systems with anticipatory capacities are much more robust than systems without them because of their better attunement.

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[5] I had to add the qualification 'authentically' to the expression 'complex system'. Mainstream complexity theories are still utterly determinist theories, while anticipatory theories need a more flexible frameworks. To better signal the difference, later on I shall distinguish 'super complex' systems from 'complex' ones.

Anticipation is the principal feature distinguishing living systems (which comprise not only biological systems but psychological and social ones as well) from non-living systems. Intuitively, as said, the choice of the action to perform depends on the system's anticipations of the evolution of itself and/or the environment in which it is situated. Non-living systems, by contrast, are reactive systems where subsequent states depend entirely on preceding ones (usually according to some rule).

The main difference between living and non-living systems is that the former require at least two layers of organization: the layer of the rules governing the system's interactions with its environment and with other systems, and the higher-order layer that may eventually change the rules of interaction. These changes may be purely random, or they may follow either pre-established or acquired patterns. In this regard, the hypothesis can be advanced that the main difference between non-living natural systems, on the one hand, and living natural systems, psychological systems and social systems on the other, is that the former systems have only one single organizational layer of interactions, while the latter have at least two layers of organization (the one governing interactions and the one capable of modifying the rules of interaction). This two-layer internal organization is precisely the structural condition that makes living systems adaptive (Poli [14]).

5. The evolution of system theory

It is well known that the development of system theory has been remarkably uneven. Moreover, different areas of application seem to adopt remarkably different ideas of system. Thirdly, the development of system theory has been hampered by some long-standing conceptual confusions. Put briefly, system theorists tend to favour an epistemological interpretation of systems as opposed to the ontologically-oriented analysis of systems. The epistemological reading claims that a system's boundaries reside in the perception of the observer, while the ontological reading claims that the systems under observation are essentially independent of the observer, who eventually discovers, or observes, them. Most confusions can be dealt with by distinguishing two aspects of the *interactions between observing and observed systems*. The thesis that knowing a system (as required e.g. by any scientific development) implies appropriate interactions between an observing and an observed system does not mean that existence or the nature of the observed system depends on the observing system, despite the significant perturbations introduced by measurements on microscopic, observed quantum systems (Baianu and Poli [3]).

A measuring device can be regarded as one of the simplest types of observing systems (Rosen [18]). The resulting *model* depends essentially on the device (e.g., on its sensitivity and discriminatory capacity). Higher-order systems require first-order systems as their constitutive elements, the basic idea being that higher-order systems result from the couplings among other, lower-order, systems. In this sense, melodies require notes, groups require agents and traffic jams involve cars.

The development of system theory can be divided into three major phases (two already completed and one ongoing). The three phases will be respectively called "the age of equilibrium", "the age of complexity" and "the age of super-complexity." The first two may be taken as lasting from approximately 1850 to 1960, while the third has rapidly developed since the late 1960s. Each phase is characterized by reference to distinct concepts of the 'general' system. Furthermore, each subsequent phase generalizes the previous one (Baianu and Poli [3]).

The first phase in the evolution of the theory of systems depends heavily upon ideas developed within organic chemistry. A system is a dynamic whole able to maintain its homeostasis, i.e., its working conditions. The relevant concept of system is spelt out by the following definition: a system is given by a bounded set of stable, interacting components.

To define a system we therefore need (1) *components*, (2) mutual *interactions* among them, (3) a marking-out of the interacting elements selected by some *boundary* which distinguishes the system from its environment; (4) with (appropriate forms of) *stability*. The latter point states that a system should last for a while: a system that comes into birth and dies off 'immediately' has little scientific relevance.[6]

The main intuition behind this first understanding of 'system' is well expressed by the following passage: "The most general and fundamental property of a system is the interdependence of parts or variables. Interdependence consists in the existence of determinate relationships among the parts or variables as contrasted with randomness of variability. In other words, interdependence is *order* in the relationship among the components which enter into a system. This order must have a tendency to self-maintenance, which is very generally expressed in the concept of equilibrium. It need not, however, be a static self-maintenance or a stable equilibrium. It may be an ordered process of change – a process following a determinate pattern rather than random variability relative to the starting point. This is called a moving equilibrium and is well exemplified by growth" (Parsons [10: 107]).

The main result achieved by the first phase of development of system theory has been proof that the system as a whole is defined by properties *not pertaining to any of its parts*—a patently *non-reductionist* view. Equilibrium (stability, etc) is a property of systems, not of their parts. However, much more than this is required to understand system dynamics. The simplest way to see what is lacking runs as follows. According to equilibrium theories, a system *is the whole* resulting from the interactions among its elements. There are at least three hidden assumptions embedded in this definition. The first assumption is that all the elements, or components, are given in advance, before the constitution of the system. We shall discuss this problem under the heading of the system's constitution. The second assumption becomes apparent as soon as one asks what happens when the set of elements changes: What happens when an element leaves the system? What happens when a new element enters the system? What happens when elements die out? This series of questions can be summarized as the problem of the system's reproduction, i.e. as the problem of the system's continuity through time, as distinct from and opposed to the continuity of its elements. The third hidden assumption is that all changes take place on the side of the environment. What about systems that are able to learn and to develop new strategies with which to survive better or to deal with other problems that they may encounter? All these problems contribute to defining the second phase of system theory, that called 'the age of complexity'.

Complexity, as usually understood, refers to chaotic systems, i.e to systems which are deterministic and sensible to their initial conditions. So understood, complex systems are entirely past-governed and are apparently unable to include anticipatory behaviour. In order to distinguish anticipatory systems from entirely past-governed systems, the concept of super-complexity has been introduced (see Baianu [2]; Baianu and Poli [3]).

6. The age of super-complexity

Living systems (which include, as said, not only biological systems but psychological and social systems as well) present features remarkably different from those characterizing non-living systems.

Super-complexity can be regarded as the most general property of living systems, including aspects like their constitution, reproduction and autonomy. In short, complex systems are systems (1) requiring a double form of composition (*the bottom-up* type of composition from elements to the system, and *the top-down* form from (a previous stage of) the system to its elements;[7] (2) capable of

[6] Claim (4) can be included under (2) by reformulating it as "repeated mutual interactions".

[7] This latter form of composition comes in two guises: (1) as constraints on initial conditions and the phase space of elements, and (2) as creation of new elements, i.e. as development of a new organizational layer of the system.

both regeneration and self-reproduction by reproducing the elements of which they are made (autopoiesis); (3) endowed with autonomy.

Super-complexity requires *at least* four different categorical frameworks, namely those provided by the theories of levels of reality, chronotopoids, (generalized) interactions, and *anticipation*. Levels of reality theory deals with the categorical framework distinguishing different families of entities (say, material, psychological and social, and then their subtypes: the physical, chemical and biological for the material stratum, the emotional and representative for the psychologial stratum and the economic, political, juridical, cultural etc for the social stratum.[8]) The idea behind chronotopoids and interactions is that each stratum of reality comes equipped with its own spatio-temporal and causal structures. Physical, psychological and social spatio-temporal and causal links are different from one another, and if their interactions are to be studied, they should be previously distinguished (Poli [14], MacIver [9]).

In this regard, a short reference may shed light on the second phase of Popper's development. Popper is famous as a champion of scientific positivism. Possibly less known is the fact that after *The Logic of Scientific Discovery*, Popper started to adopt a substantially different position, centred on a critique of the concept of determinist cause.

The first step required is to generalize the idea of force and to introduce propensities instead of forces, where the former should be regarded, not as simple possibilities, but as physical realities, as real as forces or fields (Popper [15]). Forces and causes are the *isolated*, individualized versions of propensities. The latter apply to complex situations taken as wholes.

The next step is to understand that propensities come in bundles (in layers). Just as a newly synthesized chemical compound provides the basis for synthesizing new compounds, so any new propensity is the basis for new possibilities. A world of propensities is thus an intrinsically creative world (Popper [15]).

Customary deterministic forces are nothing other than a specific case of propensity, namely the case of a maximal propensity, a propensity that always leads to the same outcome. A world of forces is a rigidified world of propensities. Whilst a world of propensities is a young, exuberant, developing world, a world of forces is an aged, unyielding one.

Changing from propensities to forces is always possible: it involves growing old. Vice versa, there is no natural way to transform forces into propensities.

The theory of levels of reality is the required framework for addressing the problem of the different spatio-temporal and causal families underlying types of propensities. Anticipation then emerges as the main feature distinguishing, as said, non-living from living systems.

7. Denying maximality

Super-complexity has a number of innovative features. The most interesting for our purposes here is the lack of maximality, i.e. the impossibility of developing a single categorical framework including all the system's relevant properties (Rosen [19]). Otherwise stated, super-complex systems can never be completely modeled.[9] They can be understood only on the basis of a number of interacting theories. We have already mentioned levels or reality, chronotopoids (ie., generalized space-time structures), interactions and anticipations as pertinent categorical frameworks. In what follows I shall outline some of the intricacies connected to the theory of anticipation.

Living systems must have the capacity to coordinate (again, as in the case of anticipation, "intentionally" or "automatically") the rhythm of the system with those of its parts. In this respect, the anticipation of the system as a whole may diverge from those of its parts. Furthermore, living systems are organized on a multiplicity of levels of organization; they are composed of different

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[8] These cases are only exemplifications. For some of the requisite details see Poli [11], [12], [13].

[9] Mathematically speaking, super complex systems require non-commutative mathematical theories, as opposed to the more customary commutative theories suitable to modeling simple and complex systems. See Baianu and Poli [3].

types of components interacting at different levels of organization.[10] Then required is analysis of both their material and functional components.

A different but not opposite way to understand anticipation is to see the theory of anticipatory systems as providing a phenomenological or first-person type of description, while most of complexity theory is usually based on third-person descriptions. The theory of anticipatory systems can therefore be seen as comprising both first- and third-person information. The interactions between the two types of descriptions may substantially reduce the state space characterizing the dynamics of anticipatory systems.

Interactions among anticipation, part-whole structures and levels of organization yield better insight into anticipatory systems (economic ones included).

8. Modeling anticipatory systems

Formally speaking, living systems, i.e. anticipatory systems, can be studied by employing the powerful tools of nonclassical, multi-valued logics and advanced mathematics. It is worth noting that such tools are the subject of continued development and application. We now have the knowledge with which to develop more general types of *space*, independently of the traditional (and widely constraining) concepts of set-membership and pointwise representation. Of great importance is the fact that the entities to be considered may be so numerous and their inter-relationships so uniform that it will be necessary to augment logic with geometrical descriptions.

The suggestion that individual and collective behavior could benefit from geometrical considerations may seem surprising at first. But in the last two centuries geometry has lost its traditional meaning of a framework for studying physical space.

In the field of action, concepts with a rich and significant geometry include: happiness perturbations across a population, subsets of the population that can be said to have “agency” and possible rankings of priorities. Agents can be individuals, but also groups of individuals, e.g. companies, groups of companies, people sharing an ideology, communities. In all these cases, the richness and abundance of elements as well as the roughly uniform relational structure between them make the geometrical approach a compact, expressive and powerful one.

For any agent, be it a single individual or a group of individuals, only a particular view of the general geometry will be relevant. Such a view will be “fovea-like” in that it will have a fine-grained core and a coarse-grained surrounding. For example, in order to evaluate the consequences of an action, one might consider the happiness perturbations to individual members of a local community (foveal), whereas only a single aggregate happiness perturbation for people of other communities might be considered. In deciding which action would be most correct, an agent could attempt to compare different patterns of happiness perturbation expressed over his/her particular community, rather than simply summing up all perturbations of individuals as in the traditional approach.[11]

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[10] See above section 4.

[11] One further advantage of geometrical approach is that it lends itself quite naturally to the development of visual decision support tools (visualization of decision landscapes). It is also worth mentioning that fovea-like vision may require non-commutativity as one of its essential formal properties. For further details see Baianu and Poli [3].

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