CORE
Metadata, citation and similar papers at core.ac.uk
Provided by PhilPapers

Libertas Mathematica (new series)
Volume 35(2015), No. 2, 1-16

Anticipation and Creation

Mihai Nadin

Abstract: The current state of an anticipatory system depends not only on previous states, but also on possible future states. In this view, anticipation is definitory of the living. Since the living is characterized by a dynamics of continuous renewal, one can say that the living is sui generis creative. It follows that all acts of creation are driven by anticipation.

Keywords: complexity, algorithmic/non-algorithmic, interaction, anticipation, reaction

MSC2010: 92B09

Dedicated to Professor Solomon Marcus on the occasion of his 90th birthday.

1 Introduction

While Turing, Church, and Gödel [1] demonstrated, each in his own way, that there cannot be an automated procedure for proving mathematical theorems, they, too, in taking Hilbert's [2] challenge, pointed towards an epistemological horizon of extreme significance for our time. Put in simple words, this horizon is defined through a question that might sound naive: "Are we pretty soon going to know–in algorithmic form–all there is to know?" (at least in the decidable world). Or, to use Wittgenstein's metaphor, is knowledge nothing but an infinitely unfolding process, as a kind of ladder, extending as we climb yet another rung [3]? Of course, this question is not by any means new, or, even less, trivial. Many scientists and philosophers have entertained its various aspects. Several have suggested analogies, such as to a time when all music was composed [4], or all poetry had been written [5], or even all possible human beings were born, and no new occurrences of the species is left. Regardless how such suggestions tickle your fancy, i.e., as speculation or as a hypothesis waiting to be tested–e.g., "Is reality nothing more than the output of computation?" would qualify in the same league–we are here in the territory called creation, regardless of whether we use the word or not.

The slippery concept, extending from the mythical, religious, and mystical–so different from one culture to another–to the most rationalist understanding embodied in algorithmic computation–an almost universal concept–is usually avoided. It comes heavily loaded with interpretations difficult to shake off. (Don't use it if you apply for a National Science Foundation grant; even at the Templeton Foundation, which claims to love an open mind, the subject is touched gingerly – my way of saying incompetently.) If *to create* is to make possible something that has not existed before–a new living entity, a recipe for a meal, a melody, a theory, an axiom, a new material, a new form of social organization, etc.–is creation infinite because of some intrinsic self-generation dynamics? Or does the process eventually come to an end due to some external forces that we might be aware of or which transcend our understanding? (Catastrophes even inspired a mathematical theory [6].) The notion of a "creator" (designer, watchmaker, or whatever) seems unavoidable, and therefore the subject is excommunicated from what is called "science." The same thing happened with vitalism–anathema to anyone suspected of having even marginally (like Schrödinger, cf. What Is Life?) something to do with it.

2 A difficult subject

In dedicating to Solomon Marcus reflections upon creation–yet another subject taboo in science, as we have seen–I most certainly considered his *oeuvre* as inspirational. More precisely, the mathematician, the linguist, the semiotician, the philosopher of culture affirmed his originality–creation is by necessity the output of originality. He approached subjects that, if not themselves taboo, were at least looked at with suspicion: mathematics and poetics; folklore and generative grammars; biology and semiotics. Marcus always addressed difficult subjects–including that of the creator. (Many great mathematicians have addressed the notion of God–which should come as no surprise if you know anything about the construct called *number*). Of course, to Solomon Marcus's *oeuvre* belongs his impeccable record of human performance. Without writing his Jewishness on his forehead, Solomon Marcus continues to be "jidanit" in a country that he genuinely identifies with. (I shall not dignify websites and authors who persist in anti-Semitic attitudes, but I cannot ignore their presence in today's Romania, or in the world, which after the horrific extermination of millions of Jews should know better.) Without ever questioning the work of his successful students, he has no qualms criticizing weak or disputable arguments. Integrity defines his profile in an Academy in which mediocrity and excellence meet. The birth pangs of a new Academy often stifle the screams of those who never produced more than noise. (Obviously, this happens not only in Romania, and not only in academic life and in the Academies.)

But enough of this. From the distance of memories, which go back almost 60 years, and from the geographical distance from which I kept my attention on his life and work, I refuse myself the luxury of judging how Solomon Marcus's Romania evolved. The Romanians are probably fond of one of their own, so dedicated to the country's future. And they should be, but not only because of his 91st birthday, rather because he is still amazingly active and up-to-date in his work. Those scientists in the world familiar with his work share in their sentiments of respect.

3 Creation conjures anticipation, not reaction

Creation implies a mother and father (even in surrogate form); and for all we know, even for asexual reproduction, this nucleus is a necessary (but not sufficient) condition. Insemination, in the broadest sense of the word, explains self-configuration, the magic of dynamic systems. This study submits the argument that each act of creation is an expression of anticipation. For this sentence to make sense, the concept of anticipation needs to be defined.

Definition 3.1. The current state of an anticipatory system depends not only upon previous states (i.e., the deterministic dimension), but also upon possible future states (i.e., the possibilistic dimension).

$$x(t) = f(x(t-1), x(t), x(t+1)) \tag{3.1}$$

Definition 3.2. Anticipation is always expressed in action.

Therefore, for the sake of building upon knowledge accumulated, sometimes anticipatory processes are modeled as control procedures. The thought that control has anything to do with anticipation comes from none other than Aristotle [7]:

> ....if every instrument could accomplish its own work, obeying or anticipating the will of others ... if the shuttle weaved and the pick touched the lyre without a hand to guide them, chief workmen would not need servants, nor masters slaves.

This describes the functioning of the human being–a synchronized whole in which the interdependence of elements is quite well documented (in medicine, but not only). A state equation serves as guidance for understanding how control processes take place:

$$A(y) = f(v). \tag{3.2}$$

In this equation, y describes the state of the system to be controlled. Of course, it belongs to a vector space Y (sometimes not easy to define). The control is described by v, and this belongs to the set of admissible controls $\mathcal{U}_{ad}$. Finally, the function f shows how the control is exercised on the system. For each $v \in \mathcal{U}_{ad}$, the state equation (3.2) has as its only solution $y = y(v)$ in Y. Therefore, to control is actually to find a value in v so that the solution to the equation describing the control system gets the system where it is intended to be. This is rather an optimal control facility than a precise controller (which is expected in machine functioning). Further down the line of this description come the feedback and feed-forward processes, and the attached timing aspects (it takes time to exercise each of them). In reality, control procedures in the physical (the world as we know it, or in artifacts of all kind) and in the living prove to be fundamentally different. In the first, determinism is unavoidable; in the second, non-determinism is characteristic.

While empirical experience of anticipation expression has accumulated over almost the entire documented preoccupation with understanding change, a coherent theory was slow in coming. An overview of works of scientific relevance in which anticipation is explicitly identified was provided in the *Prolegomena* to the second edition of Robert Rosen's book, *Anticipatory Systems* [8]. Although at the time of the writing I was able to document the work of forerunners (going back to Whitehead, Burgers, Svoboda, Bennett, Libet, among others), it took several years more to fully document the contributions of Soviet/Russian researchers [9]. What definitely surprises both the non-scientific public and researchers specialized in a variety of disciplines (e.g., psychology, physiology, neuroscience) of our time is the implicit awareness of processes in which the future plays some role. Go no further than considering our perception of change or how people handle day-to-day routines (e.g., hammering a nail, driving, sexual encounters).

Over the years, I documented anticipatory processes extending from the unfolding of the stem cell (Fig. 1) [10] to the act of creation: pregnancy (Fig. 2).

Fig. 1. From the stem cell to the never-ending variety of individuals

Fig. 2. Pregnancy: changes in the body and in the brain of pregnant women in preparation, not in reaction.

Examples of anticipation expression–ranging from "seeing" and "hearing" before seeing and hearing, motoric performance, adaptive features in plants, etc.–were given in publications explicitly focused on anticipation (Rosen [11], Louie [12], Nadin [13]) or in others focused on medicine (Latash [14], Staiger et al. [15], Hilber [15]), genetics (Delledonne et al. [15]), biology (Novoplansky [16]). But examples (i.e., empirical evidence) are not a substitute for a more comprehensive understanding of a subject. Therefore, an argument will be attempted here (in association with the opening lines): to which extent the unfolding of life (from birth to death) and our understanding of creation can be associated.

4 Is there only one Nature?

Mathematics is sometimes described as the language of nature. It provided the tools, mainly in the form of a combinatorial calculus (in particular, rules of permutation) to define how many melodies there might be possible. If one limits oneself only to melodies of a certain length (from 2 notes to 3 notes, etc.), and to a discreet distribution of notes (the 12-note scale, for example), and to whole, half, quarter, etc. notes, the number would be staggering. The life of the universe, as determined based on the best physics we know, would not suffice for generating all those possible melodies. (Here we do not include cultures with a different musical scale, and even furthermore the continuum of the sound spectrum.) In the domain of literature, the "infinite monkey" problem does not look different. But in this domain, where Borel and Edington [5], well-respected scientists, engaged in the discussion, the point was made that the subject was mechanical statistics–in other words, the mathematical description of physical phenomena. Drawing on Borel's views of the laws of nature, Arthur Edington ironically pointed out that "an army of monkeys ... strumming on typewriters...might write all the books in the British Museum, "but not overturn the laws of thermodynamics.

It is at this point that the discussion becomes interesting. Does thermodynamics apply to that all-inclusive Nature (which was Newton's concept), or perhaps only to one part of it, i.e., the physical? Of course, in the physical, there is no creation. Physical and chemical interactions, corresponding to the dynamics of lifeless matter, explain not only rain and how stone becomes sand. The energy involved in the process is the subject of thermodynamic laws, describing how order and disorder in physical processes are connected. The time scale of change in the physical realm corresponds to the nature of interactions. Indeed, Edington was right in affirming the validity of thermodynamics in the physical substratum of the world. But in the living, having its own time scale (actually a multitude), there is creation, there is originality; and the laws of thermodynamics are of limited validity (once the living dies, i.e., turns into a physical entity, thermodynamics takes fully over). In addition, there is an implicit unavoidable purpose: Let's start by taking note of the fact that the outcome is always an original (see Fig. 1).

How does the process of this unfolding take place? In a series of lectures and in some publications, Stuart Kauffman brought up some numbers: Assuming the age of the universe to be 13.7 billion years, and further assuming that the elements we are familiar with were generated by the universe itself (something along the line of the self-organization principle that is itself, in his view, some kind of Creator), we could infer to a dynamics corresponding to what we call the laws of physics. In other words, we have to arrive at the conclusion that the universe is a self-making machine. So far, so good, our explanatory models are consistent with data pertinent to how the phenomena leading to the physical world we experience unfolded. However, if we consider proteins, nitrogenous compounds of long chains of amino acids, which make up the essential part of living entities, we realize that not everything made of matter behaves the same way. Their dynamics requires that we give up the understanding of reality as one entity–Newton's inclusive Nature–and seek to characterize the physical and the living as fundamentally different. There is no one inclusive nature, but at least two (if not more). This will further help in better understanding their own change over time–each has a different time scale (the living has quite a number of them)–as well as the richness of their interactions. Indeed, the interaction between the living and the physical is of a condition different from that among physical entities (subject to Newton's gravity), or that among living entities.

Kauffman makes the point that proteins, at our current level of knowledge, are made up of 20 kinds of amino acids strung together in a linear sequence by peptide bonds. Since what he calls a "typical biological protein" consists of ca. 300 amino acids, we arrive at possible protein numbers in the range of 10^{260}. Moreover, in a universe of about 1080 particles, the making of various proteins of length 200 would require, even considering the fastest time scale (the Planck scale of 10^{-43} seconds), an age of the universe in which the assumed life (13.7 billion years) would have to be raised to the 37th power.

To make them once! [17]. Ultimately, Kauffman ascertains that the physics of the universe is of a nature different from biological processes. Long before him, Elsasser [18] (also suspected of vitalism, and ergo not found dignified enough for a Nobel Prize), attempting a scientific foundation of biology, made the same observation (while nevertheless arguing for the validity of quantum mechanics.)

In Elsasser's foundation of a science of the living, i.e., biology, there are four principles to be considered:

1. The living consists of structurally different entities, expressed in the infinite variety of cells, as opposed to the homogeneity of what makes up the atoms of the physical substratum. This is the principle of ordered heterogeneity. Individuality, which is not identifiable in physical entities, is the outcome of *ordered heterogeneity.*

2. A very large space of possible futures can be reached by these heterogenous entities. The selection is said to be always unique. This is the principle of *creative selection* (to which we shall return).

3. The dynamic patterns of the living are such that the new resembles earlier patterns without being their copy. (Think of offspring, but also think of style, associated with various forms of aesthetic expression or human typology.) This is the principle of *holistic memory*. While individual aspects remain unique, their aggregate is such that it appears to exist as a community of shared traits. The memory is not stored as data, but rather transmitted as meaning.

4. Replication and reproduction are conceived together. On the biological level, in which almost all processes are autonomous, what is passed among entities becomes subject to interpretation. The trigger is the meaning, not the data. This is the principle of *operative symbolism*.

They are kept together by the *holistic condition* of change in the living. Nobody questions that the physical substratum of the living and the non-living is the same. Short of assuming that somehow the proteins came from outside the universe (a hypothesis named *panspermia*, entertained by distinguished scientists such as Kelvin, Arrhenius, Hoyle, among others), we'd better look for models that can explain not only their presence, but also those aspects of the living that no physics can justify–at times at the price of ignoring them. For example, evolution: the emergence of design (the successful species) without a designer. (On this topic see Ayala [19] and Dawkins [20]). But the reader should be aware that the understanding mentioned, and the authors referenced, actually suggest that the living and the physical are the same, that life is reducible to matter and its laws of motion. They entirely miss the fact that the living actually co-designs its existence. And that anticipation is the process that underlies the continuous creation of one's self and maintaining one's individuality. Only with this understanding can we finally free ourselves from the epistemological chokehold of reductionism dominating the philosophy of evolution and its extension into explaining the living as nothing but a machine. Religion replaced by another religion–its high priests preaching a mechanistic view of the universe–is still dogma.

5 The future enters the picture

Anticipation is a concept that does not fit in the framework of physics. It is often reduced to prediction, which corresponds to the nature of change in the physical realm (generalization of past experience). In physics, or for that matter in chemistry, astronomy, geology, etc.), processes unfold from the past to the present within the particular form of causality we call determinism. Anticipation acknowledges that the future, as a domain of possibilities (Zadeh [21]) is part of biological processes, which are by their specific nature purposeful. There is no vitalism in this view because there is not need for it in order to explain that anticipation is the underlying reason of evolution. (Of course, this statement deserves more than just mention, but to do it justice would burst the limits of this text.)

Thesis 1: *Anticipation is definitory of the living.*

There is no need to dwell here on the many consequences of this thesis. But it is necessary to make a different point:

Thesis 2: *Causality in the physical realm is a subset of biological causality.*

Indeed, within physical determinism, laws describe repetitive phenomena–under the same initial condition, the behavior of a physical entity is always the same. In biological processes, the same causes might result in different outcomes, and more often than not in multiple outcomes.

Fig. 3. Multiple outcomes (cf. Louie [12] and Nadin [22])

Moreover, causality is by no means all-encompassing. Many changes in the living are acausal–consider the classic examples of empathy, emotional bias, dreams, for instance–or at least correlated with a variety of factors (which could be labeled *causes*, although experimentally they do not qualify as such within the definitions of cause used in science).

Creativity is but one expression of the dynamics of the living. If indeed no stem cell unfolds into a copy of what there already is–that is, if indeed the living is always an original–it is no surprise that human creativity reflects the implicit creative condition of the living. The question of every melody possible, of every poem possible, of every Shakespeare play possible, etc. is not a question of reproducibility–how to make copies–for which machines can be conceived (or an infinite number of monkeys used), but rather how to create uniqueness. In some other context, I made reference to Windelband's [23] distinction between the *nomothetic* and the *idiographic*: "der Gegensatz des Imergleichen und des Einmaligen" (the opposite of the unchanging and the unique). Without elaborating here on this distinction (anticipation is of idiographic condition), I prefer to bring into the discussion of creativity the voices of Russian/Soviet scientists (Ukhtomski, Anokhin, Uznadze, Beritashvili, among others). Early in the 20th century, challenging scientific dogma (and literally risking their lives), they understood why it was significant to examine the limits of describing change in the same terms as motion is described in physics in the tradition of Newton, Laplace, Poincaré. Explaining the dynamics of the physical, results in quantitative descriptions with predictive power (embodied in laws). Mathematics is the language for the nomothetic–the domain where we expect descriptions in the form of laws. No doubt, mathematics (in particular probability theory in its variety of flavors) undergirds prediction of physical phenomena. Explaining the living, scientists focused on motion have arrived at descriptions that capture uniqueness. The focus is on the meaning of the contingent. Mathematics must be complemented by a variety of languages adequate at capturing change in the living. The dynamics of the motoric system (or, for that matter, of the circulatory, digestive, nervous, etc. systems) elicits something along the line of historic record or a Gestalt, than of differential calculus.

The enormously successful physics of motion description in the language of mathematics is reflected in accomplishments that make up our civilization–all that was conceived (designed), built, and deployed by *Homo sapiens*. Whether it was the first tools, or the robots of our days, it all relies on the ability to take the understanding of the physical world and make it into means for further changing it. In examining the living from this perspective, i.e., in applying reductionist methods, success was also achieved, but not in the same proportion, and often times to the detriment of the living. The sustainability crisis of our times is but one example. The rapidly progressing degeneration of the species is yet a second example.

But it was not crisis, rather opportunity that informed Nikolai A. Bernstein–whose name should be associated with those mentioned above, and others–to focus on the particulars of motion expressed in the activity of the motoric system. From the rich legacy of Bernstein's work in anticipation within his focus on the motoric, I would make reference only to his formulation "repetition without repetition" [24]. It suggestively captures what distinguishes the machine–always the same–from the living–no movement, simple or not, large or imperceptible, is the same. But even more: it says that there is uniqueness to each motoric expression. In other words, creativity is endogenous, not a goal projected from outside ("Do you want to write a melody that was never heard before?"), but rather the result of successful performance (providing better selective chances). Or, in Rosen's views (defined as relational biology) closed to efficient causation (generated from within).

How can we express the particular knowledge pertinent to the dynamics of the living? Rosen and Louie (his student) chose the mathematics of category theory. Bernstein, whose activity took place before category theory was advanced (by Eilenberg and MacLane in 1945), was himself pretty adept at mathematics. However, his interaction with one of the famous Soviet mathematicians of the time, Israel Moiseevich Gelfand, proved to be consequential in more than one way in respect to the means we need for describing the change in the living. (Health is only one aspect of such change, but there are others, such as human performance.) A relatively famous formulation defines his way of thinking:

> Eugene Wigner wrote a famous essay on the unreasonable effectiveness of mathematics in natural sciences. He meant physics, of course. There is only one thing which is more unreasonable than the unreasonable effectiveness of mathematics in physics, and this is the unreasonable ineffectiveness of mathematics in biology [25].

What Gelfand says is that we need a different language for describing change in the living. At some moment in time, as we learn from Arshavsky [26], Gelfand, who contributed to neurophysiology and cell biology, asked a group of young electrophysiologists whether they believed "that neurons do not have, metaphorically speaking, a "soul", but only electrical potentials." It is complexity, of course, that Bernstein, Gelfand, Anokhin, Beritashvili, and Rosen were after. And it is in this respect that G-complexity (G, as in Gödel) was defined [27] as characteristic of the threshold of the living. G-complexity states that the living is defined as intrinsically undecidable. Since the living's expression, i.e., its creativity, is the outcome of the undecidable, we'd better stop seeking to search for answers in measurement and quantified description, and focus on evaluation of meaning. While some will cringe at the suggestion that meaning could be of relevance in understanding the dynamics of the living, let us define the term in order to avoid unjustified interpretations. In our current understanding, it is associated with semiotics, in particular with its foundation by C.S. Peirce. Knowledge is mediated by representations, which can be in language, in the formalism of mathematics, of physics and chemistry, and in the programs that drive the newest forms of machines conceived by the human mind. To speak about meaning is to interpret representation in order to gain understanding of intent or purpose, or to the sequence in time that becomes the memory of an experience. Peirce defined semiosis as the sign process and suggested that representations are subject to infinite semiosis. This means nothing other than that the sign is not a container for meaning, but a medium for interactions that define meaning. Expressed otherwise, what we do with a representation (word, image, sound, etc.) is the expression of its meaning. Obviously, meaning within semiotics is different from what Carl Jung had described ("the soul longs to discover its meaning" [28]). While the physical can be well defined in descriptions of quantitative nature (for which numbers as a particular form of signs are adequate), the living is identified through meaning, as it pertains to its maintenance. The neurons that Gelfand referred to can be described mathematically. The artificial neuron–which is based on the mathematical machined defined by McCulloch and Pitts (1943)–proved to be very useful for a particular form of computation (neuronal networks), based on which machine learning developed (reaching a spectacular level in what is called "deep learning"). But in their infinite variety, neurons don't simply pass electric or chemical signals to each other; rather, they share in the meaning of changes triggered from inside or from outside. It does not really matter whether a voltage-gated calcium channel was activated in order to release a chemical (neuronal transmitter), or if all membranes are connected by gap junctions that affect voltage changes. What counts is the meaning of such processes, i.e., this is what explains their behavior. (Of course, details are important, but this is not the context in which the N-methyl-d-aspartic acid receptors can, or should, be explained.)

Fig. 4. From the neuron (large variety) to the machine called artificial neuron (a reduction). Neurons work on account of meaning evaluation; the artificial neuron processes data (numbers).

Neuronal configurations in the human body (and throughout the realm of the living) are always in anticipation of, not in reaction to, change. Configurations change continuously: they are a generic form of creation, since they are always unique. Let us end this study taking note of the fact that creation is, after all, not the outcome of data processing, but of infinite semioses, that is, meaning processes. Such processes bridge from one biological coherent sequence–life as embodied in unique expression–to the next, always new.

Acknowledgements. A Special Faculty Development Assignment from The University of Texas at Dallas and a grant through the Hanse Wissenschaftskolleg (Germany) made possible the research for this study and the writing. Over the years, the author benefited from conversations on the subject with Lotfi Zadeh, Umberto Eco, Harry Rubin, and, more recently, Kalevi Kull and Stuart Kauffman. Joseph Weizenbaum, Heinz von Foerster, and Josef Feigenberg were also kind enough to entertain some of my ideas. Solomon Marcus heard me out more than once and drew my attention to those inferences that needed a more clear articulation. Of course, none of those mentioned is responsible for what I argue for, and even less for how well I make my arguments. In the preparation of this manuscript for publication I benefitted from help provided by Vasile Staicu, Lutz Dickmann and Carl Tape.

References

[1] Kurt Gödel (1931) On Formally Undecidable Propositions of Principia Mathematica and Related Systems: "True statements within axiomatic systems are not provable inside the system."

Alonso Church (1936) A Note on the Entscheidungsproblem, *Journal of Symbolic Logic*, 1, pp. 40-41

A.M. Turing (1936) On Computable Numbers, with an Application to the Entscheidungsproblem, *Proceedings of the London Mathematical Society*, 2:42, pp. 230-265

[2] David Hilbert (1928) Concerning the possibility of applying rules on statements of first-order logic in order to find out whether they are valid. See also: David Hilbert and Wilhelm Ackermann, Grundzüuge der theoretischen Logik (6th ed.) Berlin/Gottingen/Heidelberg: Springer, 1972

[3] The ladder metaphor is not unproblematic. In Tractatus Logico Philosophicus, we read, "My propositions serve as elucidations in the following way: anyone who understands me eventually recognizes them as nonsensical, when he has used them–as steps–to climb the ladder beyond them. He must, so to speak, throw away the ladder after he has climbed up it" (6.54) Later in his work: "Anything that can be reached with a ladder does not interest me" (MN 109, 6-17, 1930. (See Ludwig Wittgenstein, Culture and Value, Oxford: Blackwell, 1998)

[4] Is It Mathematically Possible to Run Out of New Music? The argument is relatively simple: There is only a finite number of sounds the human can distinguish. Therefore a limit could be reached where all music was exhausted. See: Ferrous Lepidoptera, Will We Ever Run Out of New Music? How many melodies are there in the universe? {http://everything2.com/title/How+many+melodies+are+there+in+the+universe?} (Accessed December 24, 2015)

[5] The Infinite Monkey Theorem –traced back to Aristotle's *On Generation and Corruption*; Cicero De Natura Deorum (On the Nature of Gods); Blaise Pascal, Jonathan Swift, Emile Borel, Arthur Edington. The monkey is a mathematical device that generates random sequences of signs. See: Emile Borel, Mécanique Statistique et Irréversiblilité, *Journal Physique*, 5e, série 3, pp. 189–196, 1913; and Arthur Edington, The Nature of the Physical World. New York: McMillan, 1928

[6] Thom, René. Structural Stability and Morphogenesis. An Outline of a General Theory of Models. Reading, MA: Addison-Wesley, 1969; and E.C. Zeeman. Catastrophe Theory, Scientific American, April 1976, pp. 65–70

[7] Aristotle. Politics, Chapter 3, Book 1. {http://genius.com/2718850.}

[8] Nadin, M. What speaks in favor of an inquiry into anticipatory processes? Prolegomena to the 2nd edition of Anticipatory Systems, by Robert Rosen, in

(George Klir, Ed.) International Book Series on Systems Science and Systems Engineering, London/New York: Springer, February 2012, pp. xv-lx

[9] Nadin, M. (Ed.) Learning from the Past. Early Soviet/Russian contributions to a science of anticipation. Cognitive Science Monographs, Vol. 25 (508 pp.). Cham, CH: Springer, 2015

[10] Nadin, M. Anticipation – The End Is Where We Start From (English-German-French text). Baden, Switzerland: Lars Müller Publishers, 2003. 129 pp.

[11] Rosen, R. Anticipatory Systems: Philosophical, Mathematical and Methodological Foundations (International Series on Systems Science

[12] Louie, A.H. The Reflection of Life. Functional Entailment and Imminence in Relational Biology. New York: Springer, 2013

[13] Nadin, M. Anticipation -The End Is Where We Start From. Basel: Lars Müller Verlag, 2003

[14] Latash, Mark, Neurophysiological Basis of Movement. Champaign IL: Human Kinetics, 2008; and Biomechanics and Motor Control: Defining Central Concepts (1st ed.) Cambridge: Academic Press 2015

[15] For the following texts, see Nadin, M. (ed.) Anticipation and Medicine. Series: Cognitive Sciences Monographs. Cham, CH: Springer (forthcoming, 2016),

Staiger, Thomas O., et al. A Conceptual Framework for Applying the Anticipatory Theory of Complex Systems to Improve Safety and Quality in Healthcare,

Hilber, Pascal. Influence of the Cerebellum in Anticipation and Mental Disorders,

Delledonne, Massimo, Marianna Garonzi, Cesare Centomo, Avinash Melahalli Veerappa From Next Generation Sequencing to Next Generation Diagnostics and Therapy.

[16] Novoplansky, Ariel. Future Perception in Plants, in Nadin, M. (ed.) Anticipation Across Disciplines. Series: Cognitive Sciences Monographs, pp. 57–70. Cham, CH: Springer, 2015

[17] Kauffman, Stuart. Foreword: Statable and Non-prestatable Landscapes, (Hendrick Richter, Andries P. Engelbrecht, eds.) Recent Advances in the Theory and Application of Fitness Landscapes. Heidelberg/Berlin: Springer, 2014, p. 8

[18] Elsasser, Walter. Reflections on a Theory of Organisms. Holism in Biology. Frelighsburg: Orbis Publishers, 1987. (Reprinted in 1998, Johns Hopkins University Press)

[19] Ayala, Francisco J. Darwin's greatest discovery: Design without designer. Washington DC: Proceedings of the National Academy of Sciences, Vol. 4, No. suppl 1, pp. 8567–8573 May 15, 2007. Published on line May 9, 2007, doi: 10.1073/pnas.0701072104 [http://www.pnas.org/content/104/suppl_1/8567.abstract]

[20] Dawkins, Richard. The Blind Watchmaker; Why the Evidence of Evolution Reveals a Universe Without Design (1st American edition) New York: W. W. Norton, 1986

[21] Zadeh, L.A. Fuzzy Sets as the Basis for a Theory of Possibility, Fuzzy Sets and Systems 1, pp. 3–28, 1978. (Reprinted in Fuzzy Sets and Systems 100 (Supplement) pp. 9–34, 1999.)

[22] Nadin, Mihai. Quo vadis Relational Biology? Review of A.H. Louie *The reflection of life: functional entailment and imminence in relational biology.* In G. Klir, Ed. International Journal of General Systems Vol. 44, No. 1, pp. 111–120, 2015 (published online 20 Dec 2014)

[23] Windelband, W. (1894). Geschichte und Naturwissenschaft, Pra'ludien. Aufsa'tze und Reden zur Philosophie und ihrer Geschichte. History and Natural Science. Speech of the Rector of the University of Strassburg), Tübingen: J.C.B. Mohr, pp. 136–160

[24] Bernstein, N.A. On Construction of Movements. Moscow: Medgiz, 1947; and Physiology of Movement and Activity. Nauka, Moscow (1990) (both in Russian)

[25] See: Borovik, A. Mathematics Under the Microscope, November 2006

[26] Arshavsky, Yuri I. Gelfand on mathematics and neurophysiology *http://www.israelmgelfand.com/bio_work/arshavsky_biomed.pdf*

[27] Nadin, M. G-Complexity, Quantum Computation and Anticipatory Processes, Computer Communication Communications & Collaboration, 2:1, 2014, 16–34. (DOIC: 2292-1036-2014-01-003-18)

[28] Jung, Carl G. Psychotherapists or the Clergy (1932). Abbreviated as CW11, para 497 in The Collected Works of C.G. Jung (R.F.C. Hull, trans.) Bollingen Series XX. Princeton University Press, 2000

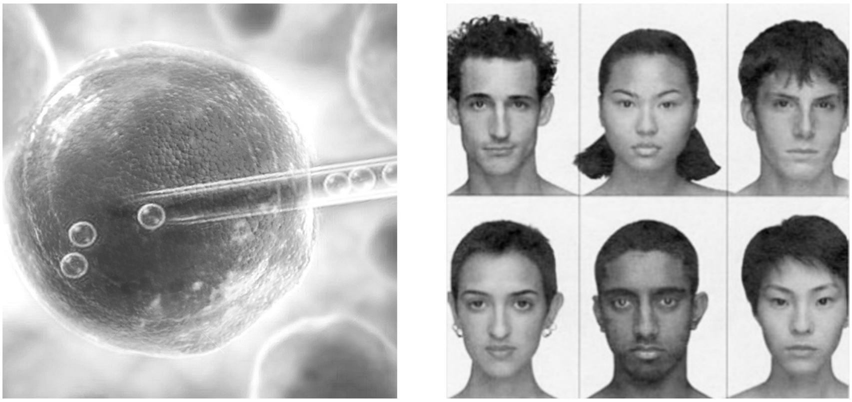

Figure 1: CAPTION

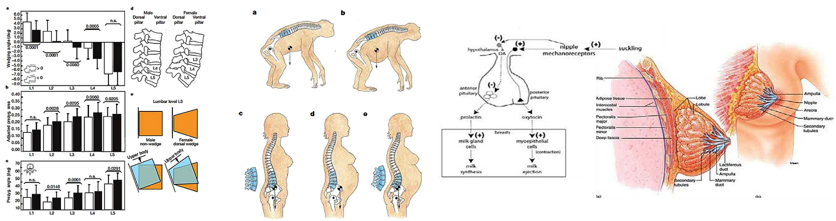

Figure 2: CAPTION

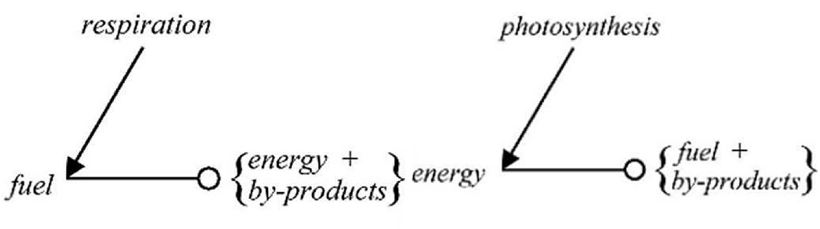

Figure 3: CAPTION

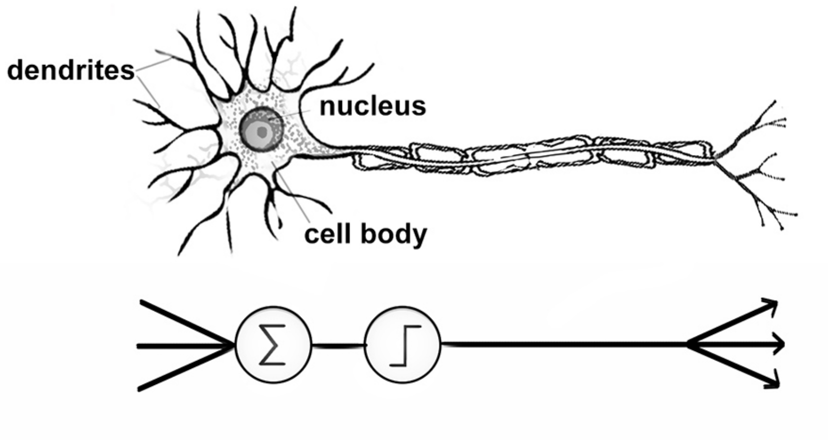

Figure 4: CAPTION

Mihai Nadin
Director, antÉ Institute for Research in Anticipatory Systems,
Ashbel Smith Professor, University of Texas at Dallas, USA
E-mail: nadin@utdallas.edu; www.nadin.ws