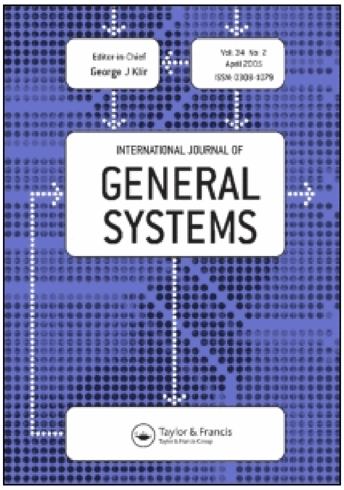

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Anticipation and dynamics: Rosen's anticipation in the perspective of time

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Anticipation and dynamics: Rosen's anticipation in the perspective of time

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Anticipation relates to the perception of change. Therefore, dynamics is the context for defining anticipation processes. Since preoccupation with change is as old as science itself, anticipation-related questions go back to the first attempts to explain why and how things change. However, as a specific concept, anticipation insinuates itself in the language of science in the writings of Whitehead, Burgers, Bennett, Feynman, Svoboda, Rosen, Nadin and Dubois, i.e. since 1929. While Robert Rosen's work is the main focus of this article, an attempt is made to advance a perspective for the broad field of studies that developed around the notion of anticipation. Of particular interest are the circumstances of epistemological and gnoseological significance, leading to the articulation of the early hypotheses regarding anticipatory processes. Of no less interest to the scientific community are questions pertinent to complexity, adaptivity, purposiveness, time and computability as they relate to our understanding of anticipation.

Keywords: anticipatory systems; ambiguity; causality; complexity; impredicativity; non-determinism

Introduction

Those familiar with the history of science are aware of the fact that, in retrospect, some theories, new concepts and new methods seemed to have been so much ahead of their time that they were either ignored or declared unviable. A very telling example in this sense is Leibniz and his digital notation. Leibniz's attempt at a universal language deserves to be celebrated as the precursor of the computer age (Nadin 1982, 1996a, 1996b, 1996c). His vision of an ideal language (*characteristica universalis*) and his *calculus racionator* effectively anticipated computation as the foundation of what today is called *the information society*. *De progressione dyadica*, dated March 1679, is a text on binary representation. His letter of 2 January 1697 shows how, in the form of a memorial coin (*Gedenkmünze*), one can establish a record of accomplishments (those of his patron, the Herzog Rudolph August) using the very precise language of only two symbols: 0 and 1 (Leibniz 1965, 1968, 1986). He used pictorial elements to compensate for the lack of expressiveness.

This example is quite clear with regard to what is needed for an idea to percolate, moreover, how often the deep roots of an idea are ignored. The practitioners of information technology – so many disciplines are based on it – will definitely not relate

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their work and expertise to Leibniz. What led to the assertion that Leibniz is the father of the digital is the powerful representation he chose. His revolutionary thought was not intended to please a patron or even to open access to Chinese writing (Leibniz 1968) – in particular the *Book of Changes* (*I-ching*) – but to overcome the ambiguities of natural language. This goal will prove to be related to the foundations of a science of anticipation, and therefore, we shall return to it.

The opening sentence alluded to discoveries initially resisted, ignored or simply rejected. Leibniz's digital machine was what we today call 'premature birth'. It was difficult to connect its implications to the given state of affairs in science. In other cases, the new ideas challenge the accepted understanding of reality. Darwin's observations in the Galapagos Islands explained variety (of finches, for instance) in terms of a process – evolution. But it took almost a century for biologists to understand his view. The fact that evolution involves anticipation justifies mentioning Darwin's case in an article focused on processes involving or resulting in foresight. More examples can be given, mainly in order to realise that delayed recognition is part of the contradictory dynamics of science. (The fact that in our days we want recognition immediately, and often get it, does not affect the argument.)

Those currently involved in the study of anticipation, or those just discovering the subject, might discard this attempt to suggest a frame of reference. The argument could be as simple as: so long as our understanding of anticipation does not continue that of the precursors, regardless of how qualified and creative they were, why bother? Indeed, if the past does not constitute a reference, the effort to reconstitute it remains, at best, of documentary significance. Leibniz's work on binary representations and on a machine capable of processing them is still practically ignored by the community of scientists and practitioners of computation. That a mathematician, Gregory Chaitin (inspired by Hermann Weyl, himself a mathematician and philosopher of science), brought Leibniz into current scientific discourse is pertinent to our subject insofar as Leibniz is identified as one of the first to dedicate his thoughts to the subject of complexity. Is Chaitin's algorithmic information theory – for which Stephan Wolfram presented him with a medal that replicates the thought of Leibniz's medallion – yet another example of a science ahead of its time? Is Wolfram's *New Kind of Science* (2002) in the same category?

Let us take note of the following: Once a branch of science becomes successful, some of its practitioners look for precursors. And often they realise that the 'wheel' to which they attached their names was invented well before. They also have the opportunity to discover in the original thoughts many paths to be pursued. To a certain extent, this holds true for the works of scholars who set forth the initial systematic considerations on anticipation. Let us mention them in these preliminary lines: Alfred North Whitehead, J.M. Burgers, J.W. Bennett, Buckminster Fuller, A. Svoboda, R. Feynman, Robert Rosen, Mihai Nadin and D.M. Dubois (the list is open and definitely subject to comment). Interestingly enough, reading the initial contributions made by such authors makes evident that representations, models, evolution, complexity and dynamics, in addition to *purposiveness*, causality and time, are part of the vocabulary deployed to make the argument in favour of a distinct scientific subject.

The annotated bibliography associated with this article documents the emergence of a 'data-rich' but 'theory-poor' field of inquiry. By no means exhaustive, the bibliography (listing publications up to the beginning of 2009) shows how far across academic disciplines' anticipation extends.

Context

Some interesting developments recommend themselves to our attention. I will introduce them almost in the style of headlines, with the intention to reconnect to them as the line of argument requires:

- 'Bacteria Can Plan Ahead Israeli Scientists Say'. Bacteria can anticipate and prepare for future events, according to new research from the Weizmann Institute of Science, which appeared in *Nature*. Researchers from the Institute's Molecular Genetics Department discovered that the genetic networks of micro-organisms could predict what comes next in a sequence of events and begin responding before its onset (Mitchell *et al.* 2009).
- Brain Imaging: 'Wave of Brain Activity Linked to Anticipation Captured' (*Science Daily*, 2009) reporting on 'Brain Activation during Anticipation of Sound Sequences' (Leaver *et al.* 2009). Neuroscientists at Georgetown University Medical Center have, for the first time, shown what brain activity looks like when someone anticipates an action or sensory input which soon follows (See also Soon *et al.* (2008)).
- Insensitivity to future consequences, after damage to the human prefrontal cortex, affects the anticipation of risk (Fukui and Murai 2005, Nadin 2009a).
- With the aim of fluency and efficiency in human–robot teams, a cognitive architecture based on the neuro-psychological principles of anticipation and perceptual simulation through top-down biasing was developed (Hoffman and Breazeal 2007, 2008a, 2008b).

This article is written in a context that can be characterised as one of missed anticipations. In this vein, Rosen should be quoted: 'I think it is fair to say that the mood of those concerned with the problems of contemporary society is apocalyptic'. Scheduled for Tuesday, 16 May 1972, Rosen's presentation, 'Planning management, policies and strategies: four fuzzy concepts' at the Center for the Study of Democratic Institutions, started with the sentence quoted above, and it applies to our times without any amendment. (We shall return to Rosen's work and to this particular article.) In this respect, let us make note of the fact that economists, as well as process control scientists, recognised early on that anticipation deserves their attention (W.I. King, W.T. Powers and G.L.S. Shackle). Their attempts can inform our current preoccupation with the broad subject of anticipation.

Almost 25 years ago, Robert Rosen's book on anticipation, *Anticipatory Systems* (1985) first reached readers. Another book (Nadin 1991) introducing the concept of anticipation was published 6 years later. The perspective of time and the evidence of increasing interest from the scientific community in understanding anticipatory processes speak in favour of describing the premises for the initial definition of anticipation. The work of Alfred North Whitehead (1929) advanced the idea that every process involves the past and the anticipation of future possibilities. This thought is part of a larger philosophic tradition sketched out (Nadin 2000) in the attempt to identify early considerations on the subject. Indeed, let us be aware of the variety of understandings associated with the concept because otherwise there is a real risk of trivialising anticipation before we know what it is. Burgers (1975) was inspired by Whitehead. Although he came from Physics, Burgers brought up choice and the preservation of freedom as coextensive with anticipation. Bennett (1976a, p. 847), an anthropologist, saw anticipation as 'the basis for adaptation'. In his book (Bennett 1976b), the same broad considerations made the subject of an entire chapter (VII), in which Whitehead's notion of anticipation, extended to the entire realm of reality, is limited to living systems. Both Burgers and Bennett are part of the broader context in which anticipation, usually used as a name holder in psychology, slowly became part of the vocabulary of science and philosophy at the end of the last century.

Feynman, famous for his contributions to quantum electrodynamics (which earned him a Nobel Prize, in 1965, shared with Julian Schwinger and Sin-Itiro Tomonaga), is probably, more by intuition than anything else, a part of the scientific story of anticipation. Feynman's own involvement with computers dated back to Los Alamos (the Manhattan Project, 1943–1945); in his biographical notes, the subject is dealt with among so many others. However, one is surprised, as he himself was, at finding out that some digitally computed data were quite different from the results produced when computing the same data in his mind – he somehow anticipated the results. He did not specifically bring up the difference made by the medium of computation, but awareness of this difference cannot be ignored. In the early 1980s, Feynman, John Hopfield and Carver Mead offered 'The Physics of Computation' course at the California Institute of Technology. Later on, interaction with Gerry Sussman (on sabbatical from the Massachusetts Institute of Technology) helped him develop 'Potentialities and Limitations of Computing Machines'. Another interaction, with Ed Fredkin, allowed him to understand the problem of reversible computation; and yet another interaction, with Danny Hillis, gave him the opportunity to become involved in parallel computing. These biographical details – and there are so many more relevant to the depth of Feynman's involvement with the subject of computation – are significant here because he, as opposed to everyone else, brought up anticipation, however indirectly, not from biology but from computation.

In an article entitled 'Simulating Physics with Computers', Feynman (1982) made relatively clear that he was aware of the distinction between what is represented (Nature – his spelling with a capital N, and nothing else, since Physics always laid claim upon it), and the representation (computation). The physical system can be simulated by a machine, but that does not make the machine the same as what it simulates. Not unlike other scientists, Feynman focused on states: the space–time view, 'imagining that the points of space and time are all laid out, so to speak, ahead of time'. The computer operation would be to see how changes in the space–time view take place. This is what dynamics is. His drawing is very intuitive (Figure 1):

The state s_i at space–time coordinate i is described through a function F (Feynman did not discuss the nature of the function): $s_i = F_i(s_j, s_k, \ldots)$. The deterministic view – i.e. the past affects the present – would result, as he noticed, in the cellular automaton: 'the value of the function at i only involves the points behind in time, earlier than this time i'.

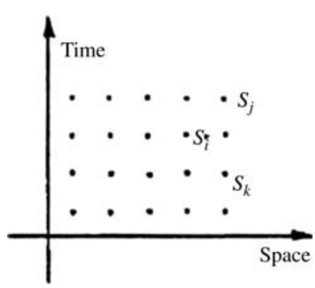

Figure 1. Feynman's [1999] original state diagram.

However – and this is the crux of the matter – 'just let's think about a more general kind of computer . . . whether we could have a wider case of generality, of interconnections . . . If F depends on *all* the points both in the future and the past, what then?'

Had Feynman posed this rhetoric question within the context of research in anticipation, the answer would be: if indeed F depends on all the points both in the future and the past, then $\rightarrow$ Anticipation. Defining an anticipatory system as one whose current state depends not only on a previous state and the current state, but also on possible future states, we are in the domain of anticipation. Feynman would answer: 'That could be the way Physics works' (his words in the article cited).

There is no reason to fantasise over a possible dialogue – what he would say, his way of speculating (for which he was famous). But there is a lot to consider in regard to his own questions. After all, anticipatory computation would at least pose the following questions:

1. 'If this computer were laid out, is there in fact an organised algorithm by which a solution could be laid out, that is, computed?'
2. 'Suppose you know this function F_i and it is a function of the variables in the future as well. How would you lay out numbers so that they automatically satisfy the above equation?'

These, again, are Feynman's words, his own questions. To make it crystal clear: the questions Feynman posed fit the framework of anticipation and computing. However, Feynman was not even alluding to a characteristic of a part of Nature – the living – to be affected not only by its past, but also by a possible future realisation. Feynman's focus was on quantum computation, and therefore the argument developed around probability configurations. When he wrote about simulating a probabilistic Nature by using a probabilistic computer, he realised that the output of such a machine 'is not a unique function of the input', that is, he realised the non-deterministic nature of the computation.

As we shall see, where Feynman's model and considerations on anticipation and computing, related to the work of Rosen and Nadin, diverge is not difficult to define. For him, as for all those – from Aristotle to Newton (*Philosophiæ Naturalis Principia Mathematica*) to Einstein – who made Physics the fundamental science it is, there is an all-encompassing Nature, and Physics is the science of Nature. In other words, Physics would suffice in explaining anticipatory processes or in computationally simulating them.

Svoboda (1960, cf. Klir 2002) published a 'model of the instinct of self-preservation' in which the subject is a computer itself. Its own functioning models self-preservation under external disturbances. A probabilistic description based on inferences from past experiences quantifies its predictive capability. Pelikan (1964) further elaborated Svoboda's original idea. Obviously, as we advance in our understanding of anticipation, there will be more contributions that, in retrospect, will deserve our attention. For example, in 1950 (cf. Gabel and Walker 2006), Buckminster Fuller taught a class at MIT in anticipatory design. (As provocative as his thoughts were, this is not the place to dwell upon them.)

In the preliminaries to define the Context, I mentioned specific contributions worthy of our current interest. The American economist Willford Isbell King (incidentally, at one time Chairman of the Committee for Constitutional Government) published *The Causes of Economic Fluctuations: Possibilities of Anticipation and Control* (1938). The circumstances (in particular, the Great Depression) explain the subject and hope. The same title could be used in our days. Fluctuations continue to haunt us, and predictive models developed so far are not very helpful when it comes to avoid dire consequences. At about the same time (1937, actually), George Shackle, under the supervision of Friedrich von Hayek, finished his dissertation, which led to his first book (1938). Expectation, as a particular form of anticipation, is connected to his future contributions to defining uncertainty. Let us take note that in examining the time vector from the beginning of an action (threshold) and the time vector from the end of the action in reverse, Shackle noticed that we never have enough knowledge in order to understand the consequences of our actions. Of interest to us today is Shackle's (1949, 1955) understanding of possibility and the contradistinction to probability. A short quote is indicative of the anticipation implications of his writing: 'It is the degree of surprise to which we expose ourselves when we examine an imagined happening as to its possibility ... ' (cf. Klir 2002a for an in-depth analysis). As far as I was able to establish, Shackle did not use the word *anticipation*, but he referred to imagination as guiding choices (1979). His conceptual contribution in understanding imagination as related to the space of possibilities will surely lead to more elaborations of interest to research in anticipation.

Possibility and its relation to probability, which was of interest to Shackle (cf. 1961), will have to wait for a more comprehensive approach until Zadeh (1978), and subsequently many distinguished followers, gave it a foundation. Zadeh himself arrived at possibility via fuzzy sets. As recently as June 2009, Zadeh, continuing his tireless investigation of the realm of knowledge he opened when introducing fuzzy sets, made note of the fact that judgement, perception and emotions play a prominent role in what we call economic, legal and political systems. Many years ago, Zadeh (1979, republished 1996) invoked the views of Shackle, among others, as an argument in introducing information granularity. This time, acknowledging complexity – which, as we shall see, is the threshold above which anticipatory behaviour becomes possible – Zadeh took a look at a world represented not with the sharp pen of illusory precision but with the spray can (spray pen geometry). Where others look for precision, Zadeh, in the spirit in which Shackle articulated his possibilistic views, wants to capture processes unfolding under uncertainty. We realise, at least intuitively, that anticipations (like imagination) are always of a fuzzy nature, and it seems to me that Zadeh's new work will make the scientific community even more aware of this condition.

It is very significant that economics prompts the type of questions that unite the early considerations of King (1938) and Shackle (1938) with Klir's considerations (2002a) and Zadeh's (2009) very recent attempts to extend fuzzy logic. Questions pertinent to economics (and associated fields of inquiry) will undoubtedly further stimulate anticipation research. We want to know what the possibilities for success are, or at least what it takes, under circumstances of uncertainty, to avoid irreversible damage to our well-being.

Volume 1 of the *International Series on Systems Science and Engineering*

The accelerated acquisition and dissemination of knowledge, in particular, the extraordinary interest in the living, are to a great extent associated with systems theory. This theory advanced a description of reality examined in its dynamics. The whole and its many components were understood in their unity. In this sense, a systems view of reality actually was a view of its functioning, i.e. of its life. At the time when systems theory emerged, a great number of high-quality scientific events made possible the meeting of scientists who usually do not meet: physicists, biologists, mathematicians and engineers.

In our days, the initial cross-disciplinary impetus is more a subject of nostalgia. Specialisation, in extreme forms, overwrites the inclination to integrate knowledge. Within this context, novelty is short lived. Books of the past are rarely read; usually they are referred to indirectly (as quoted by). Therefore, it would be naive to be surprised that the novelty of the anticipatory perspective gave way to so many minor contributions. Using the word 'anticipation' but actually missing its deep meaning characterises a great number of attempts to align with the most current research (because the fashionable attracts attention). They deserve to be fully ignored. Rosen's *Anticipatory Systems* (henceforth, *AS*) is a very telling exception. That the Editor-in-Chief of the *International Series* is still George Klir confirms his own reputation as a scholar of extremely broad perspective. In 1985, Klir had the courage and probity to publish a book submitted by a distinguished but very controversial researcher. As he himself made clear, exposure to Svoboda's ideas helped. How the book came to be published deserves a short note because science and integrity, associated with originality, cannot be conceived as independent of each other.

Rosen's manuscript eventually became the first volume in the *International Series on Systems Science and Engineering* under the heading of the International Federation for Systems Research. The Federation itself (founded in 1980) was no less controversial. In the spirit of the contributions of those who set the foundation for a system's approach (Wiener 1948, Ashby 1956, von Bertalanffy 1968), its members challenged excessive specialisation, advancing a holistic view of the world. George Klir, its first president, practiced a systems approach focused on knowledge structures. He met Robert Rosen in 1970, after visiting von Bertalanffy at SUNY-Buffalo (where von Bertalanffy, professor in the School of Social Sciences, introduced him to Rosen). They remained in touch, and between 1971 and 1972 they explored the feasibility of a new journal. In 1974, the first issue of the *International Journal of General Systems* – this very journal – was published. In acknowledging Rosen (he was in some sense a co-founder of the Journal), Klir makes note of the fact that Rosen was an active Member of the Board and published constantly from the first issue on. In 1975, an opening at the Department of Systems Science at SUNY-Binghamton prompted Klir to recommend to his Dean, Walter Lowen, that the University recruit Robert Rosen for a faculty position in the Systems Science Department. (Rosen (2006a,b), described a visit by Klir and Lowen to Buffalo in 1974.) When asked, Rosen, a scientist of high integrity, would not consider moving without his closest collaborators (Howard Pattee and Narendra Goel) at the Center for Theoretical Biology at SUNY-Buffalo. In the end, as Rosen's Center was abolished in 1975, Rosen accepted the generous offer from Dalhousie University (Killam Professor, 'like a 5-year sabbatical', as he described it) in Nova Scotia, Canada, while Pattee and Goel moved to Binghamton; they all remained in touch. In 1978, Klir published Rosen's 'Fundamentals of Measurement and Representation on Natural Systems' (Rosen 1978) in the series *General Systems Research*. Seven years passed before Rosen's *AS* appeared. Klir realised that it was a difficult text. At that time, or at any time for that matter, the book was by no means typical of publications on biology, systems theory, mathematics or philosophy. Rosen was able to fuse these in the manuscript. Klir's trust in Robert Rosen's work was the result of numerous interactions in which scholarship and character proved flawless.

Over the years, I dedicated quite a bit of time to researching the beginnings of Rosen's interest in the subject of anticipation. His own notes and some of his published works show that the early 1970s – recall Svoboda, Feynman, Burgers and Bennett mentioned in the opening lines – were pretty much the time of his attempts to specifically address the subject. In order to place the concept in the larger framework of his research, let's be more precise. Since 1957, when Rosen joined Rashevsky's Committee on Mathematical Biology at the University of Chicago, he was prepared to make relational biology the reference for his own theoretic work. His discovery of the (M,R)-systems was the starting point. In order to define the living in its concrete embodiment as organism, Rosen advanced a class of relational models called (M,R)-systems. M stands for metabolism, R for repair; and the system defines relational cell models that describe organisms. Henceforth, the object of inquiry of biology in this view is the class of material realisations of a particular relational structure expressed in the (M,R)-systems. From here on, a large body of publications bears testimony to the intellectual effort of defining what life itself is.

A material system is an organism if and only if it is closed to efficient causation (Rosen 1991). It is worth noting that the definition is focused on causality (in the Aristotelian tradition of material, formal, efficient and final causes); also, that life is embodied in organisms. What defines life is not the matter in which organisms are embodied, but what they actually do, moreover, why they do it. In his *Life Itself* (1991), Rosen dealt with the 'necessary condition, not sufficient one, for a material system to be an organism'. Complexity, which is characteristic of life, and which in the final analysis explains anticipation, 'is the habitat of life ... not life itself'. Something else is needed to characterise what is alive from what is complex (Rosen 2000). The simplest (M,R)-system is one of replication, repair and metabolism entailing one another. It is, of course, a formal representation of the living (organism, cell).

Between *AS* and his next book, Rosen's original contributions testified to a process of discovery impressive in its breadth – his subject was no more nor less than what life is, and depth – mathematical formulations meant to describe phenomena deep down to the biological molecular level. The *AS* manuscript submitted to Klir was not a stringing together of articles, but a work conceived over a long time, with many of its hypotheses subjected to discussions in various colloquia, seminars and conferences.

Robert Rosen was respected by many, but the extent to which academia accepted his work by no means reflected an understanding of its originality. Just as Leibniz's work on processing representations and on complexity was marginally acknowledged, Rosen's work, expanding well beyond anticipation, had a similar fate. It is worth mentioning that Mickulecky – who identifies himself as one of Rosen's colleagues – called him 'the Newton of biology'. The issue of *Chemistry & Biodiversity* that he edited (2007) was meant to pay homage to Rosen. Apart from the Newton–Leibniz antagonism on notation, i.e. mathematical representation, this qualifier remains inconsequential. Rosen remained, up to then, a blip on the scientific radar. Only two authors reviewed *AS*: one was a graduate student, who wrote to me that Klir stimulated him to do so; the other was a Hungarian scientist, interested in control theory. A prior book (*Theoretical Biology and Complexity*, 1985b), edited by Rosen, in which his own text brought up anticipation, was also barely reviewed and mostly misunderstood. As a matter of fact, even now, when anticipation is no longer a concept prohibited in scientific discourse, hundreds of articles are published without any direct reference to *AS*, or to Rosen, although secondary and tertiary sources – impossible in the absence of *AS* – are acrimoniously referenced. This should not be construed as anti-Rosen sentiment, rather as yet another reason to provide researchers the foundational work that gives meaning to their inquiry and helps in advancing research in the field.

The purpose of these considerations on Rosen's concept of anticipation is by no means to explain *AS*, but rather to put it in perspective. The book – which will hopefully be made available in a second edition – speaks for itself. It was written in a crisp but not facile language. After so many years since its publication, it fits quite well in the scientific discourse of our time. What changed is the context, which has broadened spectacularly. In our days, life sciences pretty much take the lead today. It is not an exaggeration to ascertain that the pendulum has swung from the obsession with Physics and Chemistry – as respectable and innovative as they still are – to infatuation with genes, cells (stem cells more than any other), protein folding and synthetic life. What has not changed is the need to understand the fundamental characteristics of the living. And this is what distinguishes Rosen from any other researcher in this domain: This is *his* perspective. The impact that *AS* has had – regardless of whether those who approach issues of anticipation are aware or not of Rosen's work – is beyond dispute. Like Svoboda, Feynman, Whitehead, Burgers and later Nadin, Rosen brought up a very controversial notion: the impact of the future on the present. For someone outside academic dialogue, this could at first appear as superfluous. Indeed, in a world shaped by the understanding of reality as reducible to sequences of cause and effect, there is little room left for acknowledging the fundamental difference between reaction and anticipation. But without this understanding, anticipatory studies have no perspective.

Dynamics of life

One of Rosen's most distinguished students, Louie (2008, p. 290) referred to the 'trilogy' Measurement–Anticipation–Life. While he was working on *AS*, which was in *status nascendi* (for almost 15 years), the three directions that Louie identified were not so well defined as in retrospect. It was very clear that Rosen's doctoral thesis, which advanced the (M,R)-systems, opened a new perspective within which anticipation is only one aspect. This needs to be brought up since in his autobiographical notes, Rosen made a specific reference: '… the (M,R)-systems have an inherent anticipatory aspect, built into their organization'. Still, as we read Rosen's *Autobiographical Reminiscences* (2006a), it becomes clear that in implicit terms, the entire focus on relational biology, in line with Rashevsky's view, is conducive to a line of inquiry that eventually questions the centuries-old reductionist-deterministic foundations of biology. Expressed otherwise, the seed of inquiry leading to anticipation is housed in the new perspective from which the (M,R)-systems are derived as a dynamic description of the living cell. This description is contrasted to the atomic model, which is reactive in nature. The biologist, the mathematician and the philosopher morph into a new type of scientist, no longer willing to further build on the Cartesian foundation, but rather taking up the challenge of submitting an alternative fundamental understanding. Rosen himself brought up the work of Schrödinger (1944), Wiener (1948) and Shannon (1948), as well as game theory, and especially Systems Theory, in particular von Bertalanffy and Ashby. Let me quote: 'To me, though, and in the light of my own imperative, all those things were potential colors for my palette, but not the palette itself' (Rosen 2006b).

Reading these names and considering the broader academic perspective of the time, we realise that somebody was left out: Walter M. Elsasser. Rosen was aware (and respectful) of Elsasser's work and occasionally referenced his writings. Elsasser is brought up here in order to provide that broader view of the work in which Rosen and many others in the field were engaged. Educated as a physicist, Elsasser made it the major focus of his work (after he arrived in the USA) to challenge the reductionist understanding of the living. His book, *The Physical Foundation of Biology* (1958, also published by Pergamon Press), followed by *Atom and Organism* (1966) and *The Chief Abstraction of Biology* (1975), was a daring attempt to look at what makes life what we know it to be. We should point out that *Reflections on a Theory of Organisms* (1987) was, by no coincidence, almost simultaneous with Rosen's *AS*. (His *Measurement* book and Elsasser's book on abstractions of biology appeared in the same year from the same publisher.) Rosen conceived the notion of anticipation in the context of his broader inquiry of life. Nadin's attempt (1991) to introduce the concept of anticipation was connected to brain research (Libet's work, 1979, 1983, 1985, on the readiness potential) and to the study of the mind (in Eccles' tradition) – what Haynes and his collaborators currently pursue. Rosen did not bring up Elsasser in his attempts to define anticipatory processes. Elsasser opposes a holistic view of the living to the reductionist model, which both Rosen, and later Nadin, challenged (with very different arguments). Elsasser proceeds from within the Physics, to which he remained loyal. His formative years (cf. *Memoirs of a Physicist in the Atomic Age*, 1977) – under the guidance of, or in interaction with, Werner Heisenberg, Wolfgang Pauli, Albert Einstein, John von Neumann, Hans Bethe, Max Born, Arnold Sommerfeld and, not to be omitted, Erwin Schrödinger – made him aware of the limitations of Classical Physics and brought him close to Quantum Mechanics. This stimulated the reformulation of fundamental biological questions. Burgers and Bennett, as well as Svoboda and Feynman, are part of a context; Elsasser, who formulated fundamental questions regarding the epistemological condition of life sciences, defines a new perspective, not unlike Rosen. The intention in juxtaposing Rosen and Elsasser is to suggest the *Zeitgeist* – spirit of the time – within which Rosen's contributions were made, in particular those leading to defining anticipatory processes. Elsasser worked on a new foundation of biology because the accepted view of considering Physics as its foundation no longer did justice to the complexity specific to the living.

To the *Zeitgeist* mentioned also belongs the activity of the Center for the Study of Democratic Institutions – the brainchild of Robert M. Hutchins, who for many years served as President of the University of Chicago. Hutchins (as cited by Rosen 1985a, p. 3) conceived the Center as an intellectual community united in the Dialogue:

> Its members talk about what ought to be done. They come to the conference table as citizens, and their talk is about the common good ... The Center tries to think about the things it believes its fellow citizens ought to be thinking about.

Among those working at the Center were political scientists, journalists, economists, historians and even philosophers, but not natural scientists. Still, Hutchins' vision and position of principle gave Rosen's presence a meaning, as he himself noted, quoting from this visionary intellectual: 'Science is not the collection of facts or the accumulation of data. A discipline does not become scientific merely because its professors have acquired a great deal of information'. And yet another:

> The gadgeteurs and data collectors, masquerading as scientists, have threatened to become the supreme chieftains of the scholarly world. As the Renaissance could accuse the Middle Ages of being rich in principles and poor in facts, we are now entitled to inquire whether we are not rich in facts and poor in principles (p. 12, Rosen 1985a, quotes from Hutchins commencement address).

This was not different from Elsasser's arguments, and was so close to Rosen's own thinking that Rosen realised that working on a theory of biological systems allowed him to formulate the characteristics of biology as an 'autonomous science', for which he would then suggest means to formalise. He made a major observation (to which we shortly alluded in discussing his definition of the organism):

> The physical structures of organisms play only a minor and secondary role ... The only requirement which physical structure must fulfill is that it allow the characteristic behaviors themselves to be manifested. Indeed, if this were not so, it would be impossible to understand how a class of systems as utterly diverse in physical structure as that which comprises biological organisms could be recognised as a unity at all.

Rashevsky's relational biology, to which Rosen adhered, stands in contrast to the then dominant analytical approach. Rosen's goal was to focus on functional aspects, on understanding behaviours. John Wilkinson, a Senior Fellow at the Center, extended the invitation to Rosen hoping that his own focus on structure would benefit from interaction with a person focused on function. The parallels between biological processes and social structures led to one of those questions that only Rosen would formulate: 'What would it mean if common models of organization could be demonstrated between social and biological structures?' (1985a, p. 13). It was very enticing for him to see a variety of disciplines finally cooperating, as it was a challenge to characterise the dynamics of life without having to account for underlying causal structures. In societal situations, the aggregate behaviour, involving a multitude of processes, appears quite differently to an observer than to those involved. No less enticing were the considerations regarding the use of social experience as a means for deriving biological insights, and reciprocally, the possibility to develop insights into properties of social systems by building upon biological experiences. Rosen confessed:

> In short, the Center seemed to provide me with both the opportunity and the means to explore this virgin territory between biology and society, and to determine whether it was barren or fertile. I thus almost in spite of myself found that I was fulfilling an exhortation of Rashevsky, who had told me years earlier that I could not be a true mathematical biologist until I had concerned myself (as he had) with problems of social organisation (1985a, p. 16).

From this attempt to establish homologies between social and biological organisation, Rosen expanded to predictive models. He realised that stimulus-reaction-based explanations could not account for situations in which subjects predict consequences of their own actions, moreover, for situations in which a course of action is changed not as a result of stimuli, but in accordance with a subject's predictive model. The switch from descriptions limited to reactive behaviour to the much richer descriptions of what he termed anticipatory behaviour resulted from a different understanding of the living. That the agency through which predictions are made turns out to be a model that corresponds to the fundamental contributions Rosen made in defining the (M,R)-systems. It was noted (by Kercel 2002, 2007, among others) that Rosen's epistemology defines properties of logical and mathematical structures. *Impredicativity* is such a property – every functional aspect of the model is contained within another functional component, i.e. definitory of the model, not of reality as such. As we shall see shortly, this is the case of the system and its model unfolding in faster than real time. This means that once we acknowledge the complexity of natural systems, we need the appropriate concepts to describe them, under the assumption that the entailment structure of a natural system is congruent with an impredicative model. But as pervasive as anticipatory behaviour is, it is not yet operational in the sense of being easy to translate into a coherent theory, and even less into applications to the problems of forecasting and policymaking that were the focus of the Center, and by now are the focus of the scientific community. The 'fortuitous chain of circumstances' described in Rosen's paper explain why his involvement with the Center can be characterised as yet another element of the spirit of the times that inspired him, as well as others (members of the Center or not), in questioning the entire analytical foundation of reductionism and determinism.

One final note about the onset of Rosen's work on anticipatory behaviour: '*Planning, Management, Policies and Strategies: Four Fuzzy Concepts*', published in May 1972, was the first of a number of working papers that define his research agenda at the Center. I already quoted the first sentence.

> It is widely felt that our social structure is in the midst of crises, certainly serious, and perhaps ultimate ... The alternative to anarchy is management; and management implies in turn the systematic implementation of specific plans, programs, policies and strategies. (p. 1)

Rosen brought up the conceptual requirements for a methodology (a 'plan for planning') that would allow avoidance of 'an infinite and futile anarchic regress'. Given the audience at the Center, i.e. none with a background in Mathematics, Biology, Systems Theory or the like, Rosen built his arguments in favour of defining anticipatory behaviour in an almost pedantic manner. But in essence, it was within this context that the major ideas of his future book on anticipatory systems were articulated. The intellectual profile of his listenership and the broad goals of the Center, which Rosen explicitly adhered to, had an impact on formulations, examples and the general tone. Aware of the fact that 'how planning could go wrong' was on the minds of his Fellows at the Center, he explicitly addressed the question, taking note of the fact that a system's integrated perspective is not bulletproof, just as 'the defect of any part of a sensory mechanism in an organism leads to a particular array of symptoms' (Rosen 1985a, p. 9, 1974, p. 250). At the centre of his conception is the 'Principle of Function Change': the same structure is capable of simultaneously manifesting a variety of functions. Rosen remained fully dedicated to his research in the foundations of biology and, in a broader sense, to the philosophical task of reconsidering the reactive paradigm. He was aware of the need to focus on what a model is and to further define the relation between a biological entity and its model; that is, the relation between something represented and its representation. It is within this broader realm that Rosen realised the urgency of understanding how an open system (the natural system) and its model – always less open – understood in their relative unity, eventually make predictions possible.

Rosen explicitly acknowledged the impact of the Center as his book came together. 'The original germinal ideas of which this volume is an outgrowth were developed in 1972, when the author was in residence at the Center for the Study of Democratic Institutions'. As a member of the Center, Rosen contributed discussion papers over many years. These texts are highly significant to our better understanding of the broad implications of research on anticipation. While the fundamental questions led to a new perspective, none of the hypotheses advanced remain exercises in formal biology. Rosen was a very engaged individual; in his own way, he was an activist. He lived his time; he wanted to understand change and he obliged explanations and even methods of improvement. It was unfair of many of the commentators of his work to see in him a rather esoteric researcher, disconnected from reality, only because his arguments were articulated in the extremely abstract language of mathematics, in particular, category theory. For the record: Rosen adopted category theory almost as soon as it was submitted to the mathematics community by Eilenberg and MacLane (1945, 1950). Rosen was a student of Eilenberg's at Columbia University, and of MacLane's at the University of Chicago.

Subjects such as planning, management, political change and stable and reliable institutions informed Rosen's presentations at the Center during the 1971–1972 academic year, when he was a Visiting Fellow. In an article published 7 years later (1979), Rosen made this explicit:

> I have come to believe that an understanding of anticipatory systems is crucial not only for biology, but also for any sphere in which decision making based on planning is involved. These are systems which contain predictive models of themselves and their environment, and employ these models to control their present activities. (p. 11)

AS followed another foundational book: '*Organisms as causal systems which are not mechanisms: An Essay into the Nature of Complexity*' (Rosen 1985b). By no means to be ignored, the other two contributions – '*The Dynamics of Energetics and Complex Real*

Systems' (I.W. Richardson) and '*Categorical System Theory*' (A.H. Louie) – make it clear that Rosen's research reached another level, and those who worked with him were encouraged to examine the various implications of higher complexity as definitory of the living. At this point, the distinction between simple systems (or mechanisms) and organisms came clearly into focus. Rosen denied, in very clear formulations, that biology is nothing more than a particular case for Physics (cf. p. 166), and argued in favour of a mathematical language appropriate to the task, which is, as we have already pointed out, category theory.

Concluding remark: 'Complex systems, unlike simple ones, admit a category of final causation, or anticipation, in a perfectly rigorous and nonmystical way' (Rosen 1985b, p. 166). It is in this very well-organised essay, of a clarity not frequently matched in his very rich list of articles and books, that Rosen defined a fundamentally new perspective. Schrödinger's question 'What is Life?' – which became the focus of his work – led to his description of 'relational biology', a concept originating with Rashevsky (1954) and which led to the realisation that only after abstracting 'away the Physics and the Chemistry' (Rosen 1985b, p. 172) we can reach the organisational features common to all living systems. Rashevsky used graphs, whose 'nodes were biological functions' and whose directed edges were 'relations of temporal or logical procedure' (Rosen 1985b, p. 172). But, as Rosen noticed, without realising his own condition, his mentor was ahead of his time:

> ... the time was quite wrong for his new relational ideas to find any acceptance anywhere. In biology, the 'golden age' of molecular biology was just beginning; experimentalists had no time or use for anything of this kind. Those who considered themselves theorists either were preoccupied with the reductionist modelling that Rashevsky had earlier taught them or were bemused by seductive ideas of 'information theory', games theory, cybernetics, and the like, regarded Rashevsky and his ideas as generally archaic because he did not take direct cognisance of their enthusiasms. (Rosen 1985b, p. 173)

A great deal of effort was spent on defining the (M,R)-systems, in particular on replication mechanisms inherent in the organisational features represented. However, the centrepiece, and appropriately so, is the modelling relation between a natural system and a formal one. Any reader of *AS* would be well advised to read Rosen's essay (even though its main line of argument reverberates in the book). It is here that the intrinsic limitations of the Newtonian paradigm are spelled out in detail. And it is here, as well, that the major subject of causality, including the teleological, is addressed up front (Rosen 1985b, p. 192). Moreover, it is here that the 'mathematical image of a complex system' comes into focus.

From the very rich text, I would like to refer to Rosen's considerations on information, specifically, on an alternate approach that relates to his preoccupation with measurement. Information, 'anything that is or can be the answer to a question' (p. 197) brought up the observation that formal logic ('including mathematics', as he put it) does not account for interrogation. Therefore, information cannot be formally characterised. Rosen used the formalism of implications (If A, then B) in order to eventually elaborate a variational form (If ζA, then B) that brought up measurement: 'If (initial conditions), then (meter reading)?' and an associated formulation on variations: If (I make certain assumptions), then (what follows?). This is, in his words, 'analogous to prediction' (p. 199). The conclusion is powerful: 'When formal systems (i.e. logic and mathematics) are used to construct images of what is going on in the world, then interrogations and implications become associated with ideas of causality (p. 199). The reader is encouraged to realise that it is exactly why the Newtonian paradigm cannot accept Aristotle's *causa finalis*, that a logical system that does not have what it takes to represent interrogation, cannot account for information that always involves a telic aspect (the ‘What for?’ of information). The idea advanced is simple and elegantly formulated:

> Like early man, who could see the earth every evening just by watching the sky but could not understand what he was seeing, we have been unable to understand what every organism is telling us. It cannot be stressed strongly enough that the transition from simplicity to complexity is not merely a technical matter to be handled within the Newtonian paradigm; complexity is not just complication but a whole new theoretical world, with a whole new Physics associated with it (p. 202).

Recalling Laplace, or better yet: challenging determinism

The question of how ideas are accepted and further developed posed in the introductory lines can be reformulated here: If a tree falls in the woods and no one is around to hear it, does it make a sound? In semiotics, one of the research fields from within which my own notion of anticipation took shape, nothing is a sign unless interpreted as a sign. The noise caused by the falling tree is a physical phenomenon corresponding to friction. It propagates at a distance that corresponds to the energy involved (the falling of a huge tree can be heard at a farther distance than the falling of a bush). The energy dissipated in the process can be measured exactly. In trying to define natural law, Laplace (1820, as quoted in Rosen 1985a, p. 9) convincingly described the kind of inferences possible in the reductionist world:

> An intelligence knowing, at a given instant in time, all forces acting in nature, as well as the momentary position of all things of which the universe consists, would be able to comprehend the motions of the largest bodies of the world, as well as the lightest atoms in one single formula. To him, nothing would be uncertain, both past and future would be present in this eyes.

In the years in which Rosen challenged a description of the world that simply does not account for the richness of life, the majority of scientists continued along the path suggested by Laplace. From this vantage point, it seems that everything is given, and with it, the laws describing it. We need only a good machine to reconstitute the past from the energy that preserved the noise of the falling tree, as it preserves all the thoughts ever expressed by those speaking to each other. Leibniz had the same take with respect to the description of a blotch of ink on white paper. It would suffice to describe the curve that interpolates the various points making up the blotch in order to obtain an image of how it came about. The oscillations of air molecules surrounding us, as they surrounded humans throughout history, could be measured. As a result of measuring such oscillations, and of course of distinguishing between all the voices, we could hear what Aristotle said, and even Socrates, whose words, we assume, Plato wrote down (or made up). Laplace guaranteed that within his deterministic view of the world, this was possible. The logical conclusion, which we tried to associate with our interpretation of the past, opened way for the hypothesis that in this universe there was some room left for considering interactions along the continuum past–present–future. The book *Mind – Anticipation and Chaos* (Nadin 1991), which paralleled *AS*, came together within the timeframe when the author realised that the concept was a necessary construct for understanding how minds interact. This scientific model also challenged the acceptance of reductionism while actually discussing a novel, Umberto Eco’s *The Name of the Rose* (and imagining that the voices of the past can be reconstituted, so that fiction and reality could be juxtaposed). The detective story was obviously written from end to beginning, or so it seems. It has a clear final cause, and it offered the author, a distinguished historian of the Middle Ages, the occasion to pose questions relevant to how representations are elaborated. Is there something there – a person, a landscape or a process – that we simply describe, draw or take a picture of? Or do we actually notice that what is alive induces changes in the observing subject that eventually result in a representation? Even within Physics, the static notion of representation was debunked as quantum mechanics postulated that to measure is to disturb. Rosen (1978) and Nadin (1959) in other ways, said: 'to measure is to be disturbed'. That is, the dynamics of the measured affects the dynamics of the measuring device.

During the tragic tsunami associated with the earthquake in the Indian Ocean in December 2004, animals vacated endangered areas for higher ground before the deadly 'harbour wave' struck (Associated Press 2004). In the same sense of 'to measure is to be disturbed', to smell, to hear or to touch is to measure, to be affected by sensorial information. The formulation, 'to measure is to be disturbed', is very descriptive of anticipatory processes. Rosen built on this knowledge, and so did Nadin (2004).

How are ideas disseminated?

Scientists often adopt an idealised model: good ideas – good lectures and presentations – good articles in peer-reviewed journals – good books – good further developments. As was already argued, in some cases, this cycle simply does not take place for a variety of reasons. Rosen, without doubt, came up with provocative ideas. His lectures and presentations confirmed his reputation. Publications made those ideas available to the scientific community. Still, no one can argue that a science of anticipation unfolded as he envisaged it would, or as many believe it should have. Furthermore, his entire work, as respected as it is by those who have cared to understand it, has not led to a recognition that translated into its further development.

Together with the rather impressive number of Center presentations (published in the *International Journal of General Systems*; see references for details) that preceded the book, *AS* invites consideration of its echo in the scientific community. Please remember the question, 'If a tree falls in the woods and no one hears the noise, does the event register as directly consequential?' It invites consideration of Rosen's essay in *Theoretical Biology and Complexity* (1985b). Let's be up front: *AS* prompted two reviews: one by Minch (1986), at that time a graduate student at Binghamton, and one by Vamos (1987) of the Technical University of Budapest (Hungary). The Essay volume (1985) prompted René Thom, the distinguished mathematician (Catastrophe Theory is associated with his name), Lee Segel (Weizmann Institute of Science), Lev Ginzburg (Stony Brook) and P.T. Saunders (King's College) to review it. In the perspective of time, this is rather little given the significance of the work. But it is also telling in respect to the difficult cognitive challenge that the work posed, and still poses. Eric Minch, now a respected researcher in his own right, might not have fully realised the impact of the radical ideas that Rosen advanced, but everything in the review is evidence of solid judgement and the desire to understand. He stated: 'The essential difference between reactive and anticipatory systems is that reactive control depends on correction of an existing deviation, while anticipatory control depends on preventions of a predicted deviation' (p. 405). Minch thoroughly referred to the *modelling relation* – 'between a natural system and a formal system' – and to their linkage. He was able to realise the importance of a new understanding of time. ('In particular, he shows how we can view models and systems as parameterised by different times', 1986, p. 406.) The book as a whole, Minch states, is both radical and profound.

> It is radical because it not only develops and propounds a paradigm, which is very different from the traditional, but also finds inadequacies in the epistemological roots of science, and overcomes these inadequacies. It is profound because of the depth of the discussion and the extent of its implications. (p. 408)

Vamos (1987) could not find anything new: ‘On reading the book, I got into the strange predicament of whether I could recommend it to my friends or not’. In the Essay reviews, Thom (1986) admired ‘an extremely interesting piece of epistemological thinking’, as well as the discussion on causality, ‘The rediscovery of Aristotelian causality theory, after centuries of blind positivist rejection, has to be hailed as one of the major events in modern philosophy of science’. Neither Segel (‘I oppose his urgings to go beyond the evolving state description that was so successful in particle physics’, 1987), nor Ginzburg (1986) realised the significance of Rosen’s model. Saunders, fascinated by the third chapter of Rosen’s text, was also taken by the novelty of the approach to causality and the non-Newtonian dynamic system.

Perspective

At this moment, even the reader most dedicated to anticipation might call into question the initiative of publishing a second edition of Rosen’s *AS*, or the intent of this article to put Rosen’s work in historical perspective. Less than enthusiastically received – but out of print, nevertheless – such an edition could re-ignite interest in the discipline’s foundational aspects. I hasten to add that my own survey of anticipation-pertinent scientific publications has resulted in a very interesting observation: very few mainstream researchers quote Rosen directly; secondary sources, in articles inspired by Rosen’s work, are usually quoted. Rosen is present, i.e. his ideas are either continuously reinvented – I can imagine him smiling about this – or, better yet, there is a definite Rosen presence even in research that is ultimately divergent from his understanding of anticipation. Here, I refer explicitly to various attempts to get machines to anticipate in one way or another – a subject to which we must return since there is so much, and often very good, work to survey.

But after all is said and done, this is not what defines Rosen as a scholar, and it would be unfair to his legacy to put more weight on the unfairness he faced than on the original thinking that defines his contribution. No scientist of integrity will lightly challenge the fundamental epistemological assumptions informing the dominant understanding of life within and outside the scientific community. Generation after generation were all educated, and continue to be educated, in the Cartesian understanding. A highly successful body of knowledge testifies to the revolutionary power of this explanatory model of the world. Still, before Rosen, and after Rosen, positions were articulated in which alternative explanations of what defines life are advanced. For a better understanding of Rosen’s original contribution, the interested reader would be well advised to consider them (they are listed in the Annotated Bibliography following this text). Given the focus on anticipation, we shall limit ourselves here to providing a context for the survey of research in the field. Rosen’s realisation of the limits of the reaction paradigm is part of his broad conception of the living. Our ability to gain knowledge about it is affected by the Cartesian perspective. To transcend this view, scientists ought to ‘discard knowledge’ (as Niels Bohr put it), and they need to see the world anew.

Informed by semiotics – which Rosen considered worthy of his attention – Nadin’s understanding of anticipation was affected by cognitive science, in particular, Libet’s work inspired by readiness potential studies. In the late 1960s and 1970s, Benjamin Libet and Bertram Feinstein (a brain surgeon) conducted experiments in which certain areas of the brain were stimulated. Fascinated by the work of Kornhuber and Deecke (1965) regarding the correlation between hand and foot movements and brain activity, Libet posed the following questions: If a simple action is prepared ahead of time by our mind (the readiness potential), at which moment do we become aware of our decision to act? (Libet *et al.* 1983). Nadin's view evolved around the mathematical model of dynamic systems. His hypotheses are: the mind controls the brain; actually, interactions of minds make anticipation possible. In fact, given some data (pertinent to an earthquake, or to a traffic bottleneck, for example), how can we infer from what happened to the circumstances prior to the events? If laws, in the sense in which we express regularities in science, could describe such events, we could predict them. Short of that, we anticipate based on the shared experience and learning.

These hypotheses also informed practical attempts in various fields of anticipation expression: communication, design, architecture, human–computer interaction and the various arts. If indeed 'the hallmark of computer systems are adaptation, self-organisation, and emergence' (Ottino 2004, p. 399), the work in the area of design was but an example of anticipation expressed in the activity of those dedicated to, and capable of, 'designing the future' (Heisenberg 1967, Furrer 1988, Nadin 1977, 1987a, b, 1998, 2009c). Discovery, relationships, facilitating connections and allowing method and intuition to complement each other are part of this activity. In 2002, the antÉ – Institute for Research in Anticipatory Systems was incorporated, and one of its first projects was a hybrid publication: book (*Anticipation – The end is where we start from*), Website (a knowledge base for the community of researchers interested in this area) and a DVD (presenting examples of anticipation ranging from chess to a simple protein folding game). The second book (Nadin 2003a) advanced a number of explanatory theories (Rosen's, of course, but also Dubois's, along with my newer attempts, integrating design knowledge, such as in Buckminster Fuller's class in anticipatory design, as well as brain imaging, to describe anticipatory processes). It suggested a number of possible fields of application – from anticipatory computing to education to self-healing materials. In particular, the loss of anticipation in the ageing and how anticipatory characteristics can be maintained became the focus of *Project Seneludens*. Through brain plasticity, stimulated by involvement in games with a cognitive and physical component, anticipatory characteristics, vital to maintaining balance and a variety of other actions pertinent to a person's independent living, can be maintained. The Institute also organised three international symposia (on subjects ranging from Vico's *Scienza Nuova*, 2005, to *Anticipation and Risk Assessment*, 2006, to *Time and the Experience of the Virtual*, 2008). The session on the relation between risk and anticipation occasioned an issue of the *Journal of Risk and Decision Analysis* (Nadin 2009b).

These details regarding the activity of the only institute dedicated to the research of anticipation are testimony to a very dedicated interest in a subject that will always have a reference in Rosen's *AS*, even if at times other views take a path different from his.

Rosen	*Nadin*
An anticipatory system is a system whose current state is determined by a future state	An anticipatory system is a system whose current state is determined not only by a past state, but also by possible future states

Given the timeframe shared by Rosen's and Nadin's early work in the field, a summarising juxtaposition is justified.

Distinguishing between prediction and anticipation is the subject that could be of further help in defining anticipatory processes. Svoboda was more focused on probabilistic-based predictions; Feynman dwelled on the same. Buckminster Fuller focused on the understanding of the future as a pre-requisite for design work. Prediction and anticipation are not interchangeable. Predictions are expressions of probabilities, i.e. description based on statistical data and on generalisations (that we call scientific laws). While not unrelated to probabilities, anticipations involve possibilities, such as those a design project involves. Zadeh's genius in defining possibility is expressed in the accepted dicta: nothing is probable unless it is possible. Not everything possible is probable. The model of itself, that unfolds in faster than real time, in Rosen's definition (1985a) is driven by both probability realisations and possibility projections. It is with respect to this fundamental distinction that Nadin submitted the thesis according to which the complementary nature of the living – physical substratum and specific irreducible dynamics – is expressed in the complementary nature of anticipatory processes (Nadin 2009c). Moreover, his attempts to quantify anticipatory processes (through the AnticipationScope™, in the framework of Project *Seneludens*, Nadin 2004) guided my continuous attempts to seek mathematical descriptions that transcend classical measurement (attaching numbers to variables). So far, a good candidate for this attempt proved to be Goldfarb's Evolving Transformational System – ETS (Goldfarb *et al.* 2007). This note cannot end without explicitly acknowledging Zadeh's attempt (2003) to describe anticipation as a particular form of perception-driven computation. He is acutely aware of the role perception plays in anticipation and I suspect that in the years to come, his ideas on perception-based computation will benefit anticipatory systems research at least as much as fuzzy set theory has benefited science and engineering.

The next generation

From the rather large broad database of contributions to a possible discipline of anticipation, selection of some as better or more appropriate than others would be preposterous. To further compartmentalise them based on their subject matter would probably give a good indication of the breadth of the scientific inquiry. The choice that is pertinent to my comments is a simpler one: studies pursuing Rosen's theoretic outline, and studies defining the field in ways other than his own; or better yet, what he called pseudo-anticipation. No author could claim credit for a full account. We can more easily find what we look for, but at times to formulate the question is more challenging than to advance a hypothesis as an answer. Example: Ishida and Sawada (2004) report on a very simple experiment of human hand movement in anticipation of external stimulus. Unfortunately, while actually reporting on anticipation, the authors never name the concept as such. (It is from this experience that the author discovered how many Japanese scientists would be happy to have access to a new edition of *AS*, and to a good theory of anticipation.) In other cases, anticipation, the word, is present, but the results presented have actually nothing to do with it. In a different context (Nadin 2003b), the distinction between anticipation, prediction, expectation, forecast, etc., was made, insisting on the fundamental difference between inferring from the past (on the basis of a probability distribution) and integrating the past and the possible future. It is useless to single out even one example because, after all, there is nothing to object to what is presented, rather to the use of a concept that has, after Rosen's *AS* and after some contributions brought by others, a precise meaning.

That the scientific community at large has not embraced the view reflected in this particular interpretation means only that more has to be done to disseminate the word, in conjunction with its understanding. Einstein's assessment – 'No problem can be solved from the same consciousness that created it' – is relevant not only for those willing to step out from their epistemological cocoon, but also for those who literally cannot find useful answers within the epistemology they practice.

Classical research in psychology – in particular, on receptive-effector anticipation (Bartlett 1951) – prepared the way for perceptual control theory (PCT) initiated by Powers (1973, 1989, 1992) around the notion of organisms as controllers. Kelly's (1955) constructivist position is based on validation on terms of predictive utility. Coherence is gained as individuals improve their capacity to anticipate events. Since the premise is that knowledge is constructed, validated anticipations enhance cognitive confidence and make further constructs possible. In Kelly's terms (also in Mancuso and Adams-Weber 1982), anticipation originates in the mind and is geared towards establishing a correspondence between future experiences and predictions related to them. The fundamental postulate of this theory is that our representations lead to anticipations, i.e. alternative courses of action. Since states of mind somehow represent states of the world, anticipation adequacy remains a matter of validation through experience.

Anticipation of moving stimuli (Berry *et al.* 1999) is recorded in the form of spike trains of many ganglion cells in the retina. Known retinal processing details, such as the contrast-gain control process, suggest that there are limits to what kind of stimuli can be anticipated. Researchers report that variations of speed, for instance, are important; variations of direction are less significant.

That vision remains an area of choice in identifying anticipation is no surprise. An entire conference (University of Dundee, 2003) was dedicated to Eye Movements – considered 'a window on mind and brain' – while the European project *MindRaces: from reactive to anticipatory cognitive embodied systems* encouraged studies in this field, given its applied nature (Pezzulo *et al.* 2007a, 2007b). Balkenius and Johanson (2007) contributed to the project the research of anticipatory models in gaze control, integrating reactive, event-driven and continuous-model-based location of target. Obviously, learning (with contributions from Butz, among others) in the view of the group is rather different from Rosen's notion, but it is encouraging to notice that the recognition of the role of learning extends to their domain of interest.

Arguing from a formalism, such as Rosen used, to existence is definitely different from arguing from existence (seeing, hearing, binding of the visual and aural, etc.) to a formalism. A vast amount of work (concerning tickling, e.g. Blakemore *et al.* 1998; posture control, e.g. Gahery 1987, Melzer *et al.* 2001, Adkin *et al.* 2002; gait control, e.g. Sahyoun *et al.* 2004) exemplifies the latter. The very encouraging aspect here is that measurements of trigger-based experiments reveal what happens before the trigger; in other words, in anticipation of stimuli, not as a result of them. We can only be doubtful that from these rich sets of data a theory of anticipation, or at least some amendments to the available theories, will emerge. But I am encouraged by the experimental evidence, first and foremost because it supports the fundamental idea expressed in Rosen's modelling relation: if a modelling relation between a natural system and a formal description can be established, the formal description (of vision processes, of tickling, of tactility, of sound and image binding, etc.) is a model, and the domain knowledge is a realisation of such a description subject to further investigation. Moreover, arguing from computation – which is more and more a gnoseological mode – might impress through even broader sets of data and much more detail, but still not substitute for the lack of a theoretic foundation.

As impressive as are, among others, applications in neural networks (Homan 1997, Knutson *et al.* 1998, Kursin 2003, Tsirigotis *et al.* 2005), artificial intelligence (Ekdahl *et al.* 1995, Davidsson 1997) and adaptive learning systems (Butz *et al.* 2003), they can at most make us even more aware of the need to define our terminology and practice scientific discipline. Rosen (1991, p. 238) pointed out quite clearly that the more constrained a mechanism, the more programmable it is. Albeit, reaction is programmable, even if at times it is not exactly a trivial task to carry out. Modelling and simulation, intensive computational tasks, are no more anticipatory than any other mechanisms. They embody the limitation intrinsic in the epistemological horizon in which they were conceived. Neural networks and anticipation followed by impressive achievements in animation and robot motion planning (Balkenius *et al.* 1994, Christensen and Hooker 2000, Fleischer *et al.* 2003) only allow us to realise again the line between purposive activities (where there is a *telos*, a finality) and deterministic activities, of a different causal condition.

This observation brings up the impressive effort known under the name *CASYS conferences* (organised by D.M. Dubois, in Liege, Belgium since 1997). Disclaimer: After a very encouraging beginning, based on reciprocal respect, Dr Dubois and the author found that there was an incompatibility in our respective perspectives of anticipation, and probably beyond our respective science. He is a trained physical engineer, of oft-acknowledged accomplishments. Dubois fully realised that Rosen's concept of anticipation is antithetical to the conference agenda – which is also his personal agenda[2]. Dubois builds upon McCulloch and Pitts (1943) 'formal neuron', and on von Neumann's suggestion that a hybrid digital–analogue neuron configuration could explain brain dynamics. It is tempting to see the hybrid neuron as a building block of a functional entity with anticipatory properties. But from the premise on, Rosen followed a different path, quite convincingly, that recursions could not capture the nature of anticipatory processes (since the 'heart of recursion is the conversion of the present to the future'). Neither could incursion and hyperincursion (an incursion with multiple solutions) satisfy the need to allow for a vector pointing from the future to the present. Rosen warned about the non-fractionability of the (M,R)-systems; and this is of consequence to the premise adopted in Dubois's work. When Dubois (2000) defines '... the main purpose ... is to show that anticipation is not only a property of biosystems, but is also a fundamental property of physical systems', he argues with Rosen's fundamental ideas from a position that basically denies the epistemological foundation of *AS*. Within science, this is perfectly acceptable, provided that the concepts are coherently defined. Unfortunately, this provision is ultimately not met. For particular applications, Dubois's take is quite convincing, and his work attracts followers. Addressing issues of autonomous systems (i.e. they self-regulate), Collier (2008) builds on Dubois's conjecture in addressing autonomy and viability. Suffice it to say that such a contribution, although by no means in Rosen's perspective, is in itself relevant for the richness of the dialogue that Rosen's book and its subsequent interpretations triggered. We can only hope for the broadening of the conversation. Leydesdorff (2008, 2009), exceptionally active in social applications and communication (in particular, meaning), also built on Dubois's model, is fully aware of Rosen's initial definitions.

Along this line, it is useful to mention some very convincing attempts to relate perception and motoric response (Steckner 2000) to address issues of predictive model generation (Riegler 2001), to associate anticipation with decision-making processes and to deal with interaction as it results in a variety of anticipatory processes (Kindler 2002). In the area of applied interest (automobile driving, assessing the impact of emerging technologies, extreme events assessment, the whole gamut of applications in the

MindRaces program), authors from various backgrounds (Nadin 2005, 2007, Butz *et al.* 2007, Munduteguy and Darses 2007, Myers 2007, Pezzulo 2007a, 2007b, among others) advance cognitive and information processing models that contribute to the current interest in pseudo-anticipatory processes. It is significant that Zadeh (2001, 2003) made the connection between computing with perceptions and anticipation. von Glasersfeld (1995) framed anticipation in the constructivist theory of cognition. Pribam (2000) considered free will and its relation to the brain as an anticipatory system. Klir (2002b) evaluated the role of anticipation in intelligent systems.

More recently, within the same interest in fundamental aspects of the subject, issues related to health have been examined from the perspective of anticipation (Berk *et al.* 2008, research at the Oak Crest Health Research Institute, Loma Linda, CA, USA). The hypothesis that major neuro-motoric disorders (Parkinson's disease, in particular) are the result of skewed anticipation was advanced in an application to an NIH Pioneer grant (Nadin 2007). In respect to this hypothesis, the issue of time and timescale was brought up (Rosen and Kineman 2005), while brain imaging (Haynes 2008) allowed a very telling visualisation of decision-making processes. Before that, van Boxtel and Böcker (2004) addressed the efficiency of cognitive processes, reviewing 15 years of Stimulus Preceding Negativity (SPN) research. They specifically confirm the role of anticipation in everyday life situations. Cortical potentials are invoked in relation to a subject's preparedness. Spectacular results were also communicated (Whitcome *et al.* 2007) regarding the increased anticipation associated with pregnancy.

It is evident that these examples, by no means even close to complete, are only additional arguments in favour of a robust research programme.

Models, non-trivial machines, ambiguity

Evidence from experiments, which has multiplied beyond what was imaginable during Rosen's life, places the subject of anticipation in what Kant called the *apodictic*: certain beyond dispute. But the same holds true for physical reductionism. Rosen was fully aware of this epistemological conundrum and accordingly tried to justify the legitimacy of a science of anticipation as part of a broader science – that of organisms (the 'living sciences' or 'life sciences' of our days). There is no doubt that *What Is Life?* – characterised as a 'Fair Scientific Question' – turned out to be for him the 'central question of biology' (Rosen 1991, p. 25), and the pinnacle of his entire activity. Within his understanding, life emerges beyond the finite threshold of complexity. Impredicativity and non-fractionability are related because they describe the living in its unity. Therefore, the reader would be well advised to read *AS* in conjunction with *Life Itself*. This is an opportunity that the original readers (in 1985) did not have (at least for 6 years, until *Life Itself* was published). Only in associating the two can one derive the understanding of the role anticipation can play in furthering science.

In reporting on the rich variety or research directions in anticipation today, we were looking less towards finding arguments in favour of discipline or in emphasising Rosen's contributions (some still the object of dispute), and more in the direction of acknowledging variations in the meaning of the concept. Wolkenhauer (2008) suggestively gives the following description: 'Robert Rosen was ahead of his time with his investigation into the dialectical relation between mathematical models and computer simulations of cells'. He himself names Rosen as a central figure in his career, and therefore cannot be suspected of undermining his thoughts. Mathematical models, as Rosen advanced, were not reducible to computer simulations. The dialectical relation that Wolkenhauer suggests might indeed allow for further dialogue between the strict-Rosen followers and the computational-oriented new generation of researchers. Rosen's strict terminological discipline should, of course, not be construed as a declaration of ownership. My own view of anticipation, which highlights non-deterministic processes, as well as anticipation as a realisation in the space of possibilities, probably differs from his. The understanding of anticipatory processes as definitory of the living is shared by a minority of those pursuing the subject. But this is science, always subject to subsequent revisions and re-definitions, not religion or a dogmatic pursuit of pure terminology. It would benefit no one to proceed in an exclusionary manner. Knowledge is what we are about and, in the long run, our better understanding of the world and of ourselves is the final arbiter. In this sense, it can prove useful to our understanding of Rosen's contribution and the richness of attempts not aligned with his rigorous science, to shortly acknowledge yet another fascinating scientist whose work came close to some of Rosen's interrogations: Heinz von Foerster. We were unable to find out whether the two of them met. von Foerster was associated with the University of Chicago for a while; his Biological Computer Lab at the University of Illinois-Urbana Champaign could not have escaped Rosen's attention. Moreover, his original writings (in establishing Second Order Cybernetics) definitely caught Rosen's attention. von Foerster himself was aware of Rosen's work and found the subject of anticipation very close to his own views of the living and on the constructivist Condition of Knowledge. But what prompts our decision to bring up von Foerster is the striking analogy between Rosen's model (1985a, p. 13) and von Foerster's concept of non-trivial machines (von Foerster and Poerksen 2002) (Figures 2 and 3).

Let us only make note of the fact that non-trivial machines are dependent on their own history (which is the case with Model M in Rosen's model), cannot be analytically determined, and are unpredictable (cf. von Foerster and Poerksen 2002, p. 58).

If the suggestion holds – and we should dedicate more time to it – it is quite clear how from the original Rosen definition of anticipation, many more, derived as alternative non-trivial machines (in von Foerster's sense, i.e. non-algorithmic), were conceived and tested. Sure, this brings up important epistemological questions, from among which I would only allude to one: replication. Howard Pattee, his colleague at the Center for Theoretical Biology in Buffalo, still cannot accept Rosen's intransigence in dealing with von Neumann's universal constructor – a construct that could achieve unlimited complexity. Pattee is willing to concede that formally von Neumann's model (which he – Rosen n.n. – thought it

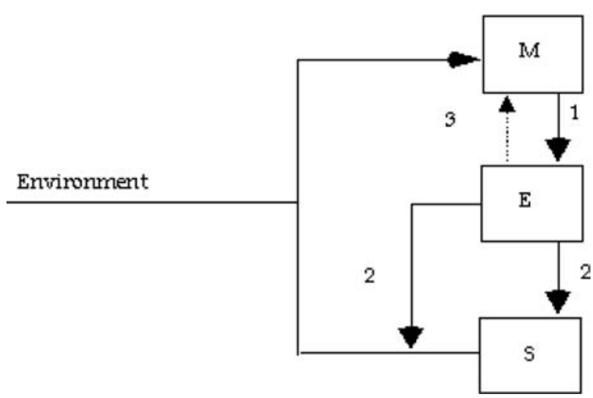

Figure 2. Rosen's (M,R)-model.

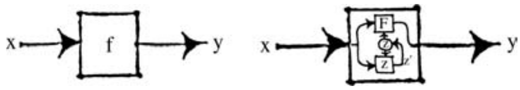

Figure 3. 'Roadsigns definitions postulates aphorisms, etc.' [sic] (von Foerster 1995).

competed with his own (M,R)-model) was incomplete. But he argues that actually, von Neumann and Rosen agreed (life is not algorithmic). Moreover, that self-assembly processes characteristic of the living do not require complete genetic instructions. The reason for bringing up this point is rather practical, and Pattee (2007) expressed it convincingly: we should avoid getting diverted from Rosen's arguments only because, at times, they do not conform with the accepted notions (in this case, von Neumann's replication scheme).

Rosen (1966) was actually opposed to von Neumann's understanding of the threshold of complexity, bringing up the need to account for the characteristics of the organism as evolvable. Nevertheless, in hindsight we can say that both realised, although in different ways, that if complexity is addressed from an informational perspective, we end up realising that life is ultimately not describable in algorithmic terms. Chu and Ho (2006) correctly noticed that, in Rosen's view, 'living systems are not realizable in computational universes'. They provided a critical assessment of Rosen's proof, which Louie (2007) refuted. Louie's argument in some ways confirms that non-algorithmic self-assembly (epigenetic progresses) is of such a condition that it does not require either full descriptions of the functions or of the information involved in living processes.

Given the implications of this observation, we need to give it a bit more attention. Along the line of the Church-Turing thesis – i.e. that every physically realisable process is computable – von Neumann (1963, p. 310) went on out a limb and stated, 'You insist that there is something a machine cannot do. If you will tell me precisely what it is that a machine cannot do, I can always make a machine which will do just that'. If von Neumann was convinced that telling *precisely* what it is a machine cannot do – emphasis on *precisely* – is a given, he was not yet disclosing that *telling precisely* might after all require infinite strings, and thus make the computation to be driven by such a description impossible (*intractable*, in computer science lingo). Actually, von Neumann should have automatically thought of Gödel in realising that a complete description, which would have to be non-contradictory, would be impossible. Descriptions, in words (as he expected, cf. 'anything that can be completely and unambiguously put into words ... '), or in some other form, are, in the final analysis, semiotic entities. They stand as signs for something else (the represented), and in the *interpretant* process we understand them as univocally or ambiguously defined (Nadin 1988).

Representations of the world, not fragments of the world, are actually processed. Until the development of brain imaging, we could not capture the change from sensorial energy to the re-presentational level. And even with images of the brain, we still cannot quantify semiotic processes. It is the re-presentation of things, not things themselves, that is subject to processing and understanding. Re-presentations are renewed presentations as signs; that is, attempts to associate a sign to an object and to conjure the consequences that the sign might have on our activity. Re-presentations can be of various degrees of ambiguity – from very low (indexical signs, as marks left by the object represented) to very high (symbols, i.e. conventions). Lightning arouses a sense of danger associated with phenomena in the world. The black cat brings up false associations (superstitions) with dangers in the world. They are of different levels of ambiguity. The living can handle them quite well, even if, at times, in a manner we qualify as irrational. Machines operate also on representations, provided that they are unambiguous. For this reason, we conceive, design, and deploy artificial languages of zero or very low ambiguity. The living operates, most often effectively, with representations regardless of their ambiguity. The machine is 'protected' from ambiguity. (We endow machines with threshold identifiers: is the ignition turned on or not? Intermediate values do not count! Ambiguity is a source of error in their functioning.) von Neumann's claim that he could conceive a computation for any *precisely* described entity means nothing more than that he proceeds to segregate between the semiotic of the unambiguous and the semiotics of ambiguity.

In addition, computational reductionism does not acknowledge the fundamental role of time in the dynamics of the living. It can be proven that an anticipatory system has at least two clocks, i.e. correlated processes unfolding at different times scales (Nadin 2009c). Rosen and Kineman (2004) examine the characteristics of complexity in Rosen's view, realising correctly the central role played by the modelling relation. 'The internal predictive models' are, in their view, hypotheses about future behaviour. Finally, Feynman's understanding (1982) of the integration of past, present and future in the computation (meant to simulate Nature) is probably closer to Rosen's understanding of anticipation.

With all these considerations in mind, the reader should now be in a better position to understand that at the level of simple machines, anticipation is not possible. Such simple machines operate in the interval domain of causes and effects, in a non-ambiguous manner.

Once we reach the threshold of complexity at which causality itself is no longer reducible to determinism, and the condition of the living integrates past, present and future, a new form of adaptive behaviour and of finality (*purposiveness*) emerges that makes anticipatory processes possible, although only as non-deterministic processes (after all, anticipation is often wrong).

Life is process (to recall Whitehead, among others), more precisely, non-deterministic process. This makes the role of the physician, and of the economist for that matter, so difficult. Therefore, in addressing causality with respect to the living (a person's health, the state of the economy), we need to consider past and present (cause–effect, and the associated reaction), both well defined, in conjunction with a possible future realisation, ill defined, ambiguous. When we have to account for higher complexity – the threshold beyond which reaction alone can no longer explain the dynamics – the anticipatory component must be integrated in our understanding. In logic (Kleene 1950), an impredicative definition is one in which the definition of an entity depends on some of the properties of the entities described. The definition of life is an example of *impredicativity*; that is, it is characterised by complexity which in turn is understood as a threshold for the living. Impredicative definitions are circular. Kercel (2007) noticed that ambiguity is an observable signature of complexity. He goes on to connect this to the issue of prediction: 'ambiguity of complexity shows that the "unpredictable" behaviours of complex systems are not random, but are causally determined in a way that we (having no largest model of them) cannot consistently predict'. These words describe anticipatory dynamics.

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Notes

1. M. Nadin is an Ashbel Smith University Professor and Director of antÉ – Institute for Research in Anticipatory Systems.
2. After a very encouraging beginning, based on reciprocal respect, Dr Dubois and the author found that there was an incompatibility in our respective perspectives of anticipation, and probably beyond our respective science. He is a trained physical engineer, of oft-acknowledged accomplishments.

Notes on contributor

Mihai Nadin's education, interests and professional life combine engineering, mathematics, digital technology, semiotics, theory of mind and anticipatory systems. He holds advanced degrees in Electrical Engineering and Computer Science and a post-doctoral degree in Philosophy, Logic and the Theory of Science. His book, *Mind – Anticipation and Chaos,* introduced original ideas in the fields of mind and education (ideas confirmed by later independent studies). Research in dynamic systems and mind functioning at Stanford University led Nadin to search more deeply into anticipatory systems. His research at UC-Berkeley led to several articles (e.g. 'Anticipation – A Spooky Computation', 'Anticipating Extreme Events: the need for faster-than-real-time models') and the book, *Anticipation – The End Is Where We Start From*, that sets a foundation for the field in lay terms. In 2002, he established the antÉ – Institute for Research in Anticipatory Systems. It also worked as a 'think tank', and consulting entity (for technical innovation, business, policy development, game-based simulations, defence). The Institute became part of the University of Texas at Dallas in 2004, when Dr Nadin accepted the university's invitation to become an Ashbel Smith University Professor. Dr Nadin is carrying out research on capturing anticipatory characteristics and on quantifying anticipation in the AnticipationScope™. The Project *Seneludens* focuses on developing devices to maintain the anticipatory capabilities of the ageing population. Dr Nadin was invited by the Collaborative Research Center at the University of Bremen to participate in the project Autonomous Cooperating Logistic Processes, in particular in the area of intelligent multi-agent societies endowed with anticipatory characteristics (Spring 2010). For more information, see www.nadin.ws and www.anteinstitute.org.

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