

2 Anticipating Extreme Events

Mihai Nadin

Summary. The urgency explicit in soliciting scientists to address the prediction of Xevents is understandable, but not really conducive to a foundational perspective. In the following methodological considerations, a perspective is submitted that builds upon the necessary representation of Xevents, either in mathematical or in computational terms. While only of limited functional nature, the semiotic methodology suggested is conducive to the basic questions associated with Xevent prediction: the dynamics of unfolding Xevents; the distinction between Xevents in the deterministic realm of physics and the nondeterministic realm of the living; the foundation of anticipation and the possibility of anticipatory computing; the holistic perspective. As opposed to case studies, this contribution is geared towards a model-based description that corresponds to the nonrepetitive nature of Xevents. Therefore, it advances a complementary model of science focused on singularity, providing a nondeterministic understanding of high-complexity phenomena.

2.1 The Representation of Extreme Events

Let us imagine that somehow we could fully capture an Xevent – an earthquake, a stock market crash, a terrorist attack, an epileptic seizure, a tornado, a massive oil spill, a flood, an epidemic or any other occurrence deemed worthy of the qualifier “extreme” (the kinds of measurements and other observations that qualify the result as extreme will remain unanswered for the time being). Based on what we know today – aware more than ever that everything is in flux (“Panta rhei”, to quote Heraclitus [1]) – and on the scientific models that presently guide knowledge acquisition, we understand that to fully capture (represent) an event (extreme or not) involves not only explaining it, but also ultimately being able to reproduce it. This is another way of saying that if we could adequately represent an Xevent, we would be able to predict it and similar events, as well as their consequences. Implicit in this perspective is the expectation of determinism, a particular form of causality. More precisely, the representation contains the description of the cause or of the causal chain. Obviously this is no longer a case of simplistic representation of cause and effect, but one tempered by the realization that only an acknowledgement of a rich variety of causal mechanisms can explain the broad dynamics of complex phenomena. After all, the common denominator of Xevents is their complexity.

With all this in mind, let us denote the full description of an Xevent as its *representamen*, R . (The informed reader will have already noticed that this unusual word comes from Charles S. Peirce [2].) There are no limitations upon what R can be. It can be a record of quantities (numbers – the set N of natural numbers); it can be an event score (similar to a music score or to a detailed film script). It can be a completed computation – assuming that the algorithm/s behind the computation is/are tractable, that is, that they have a polynomial solution in the worst case. It can be a computation in progress, about to reach a halting stage, or reaching one in several generations (an evolutionary computation). It can be a combination of some or all of the above, plus anything else that science might come up with. Regardless of what R is and how it was obtained, if we could fully capture an event, we could also understand how the event – henceforth called the object (and denoted O) for reasons of convenience – and its representation relate to each other (in other words how a change in R , the representamen, might affect a change in O , the event reproduced or anticipated). This understanding (by a human being, a scientific community, a computer program, or a neural network procedure), called I for *interpretant process* (according to the same Peircean terminology already alluded to), is actually all that society expects from us as we dedicate out inquiry to Xevents. Indeed, we are commissioned (some explicitly, others implicitly) to conceive of methods for predicting Xevents. Based on such predictions, society hopes to avoid some of their consequences, or even to avoid the event (in the case of, say, a terrorist attack or an epileptic seizure).

The three entities introduced so far – R for representamen (the plural is *representamina*), O for object (to be defined in more detail), and I for interpretant – are derived from Peirce’s semiotics. For the scientist wary of any terminology that does not result from some specialization (such as the many mathematical branches growing on the trunk of *mathema*, the various theories of physics, the biological fields of inquiry such as molecular biology or genetics, and so on), a word of caution: regard the entities introduced so far only as conceptual tools, and only in conjunction with the descriptions given so far. Actually, their relationship can be conveniently illustrated thus:

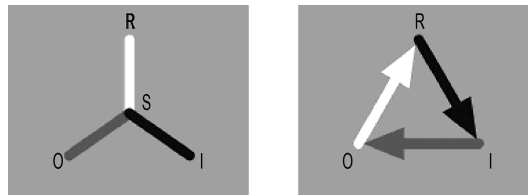


Fig. 2.1. A sign is something that stands for something to someone in some form or capacity (see C.S. Peirce, [3–5]). The two diagrams represent two views: on the *left*, the sign as a structure $S = S(O, R, I)$, and on the *right*, the sign as a process that starts with a representation (R of O) to be interpreted in a sign process

The diagrams tell a very clear story: “In signs, one sees an advantage for discovery that is greatest when they express the exact nature of a thing briefly and, as it were, picture it; then indeed, the labor of thought is wonderfully diminished” (Leibniz as cited by Schneiderman [6]).

An unusual scientist, grounded in mathematics, astronomy, chemistry, logic, and geodesic science, Peirce considered natural phenomena, as well as social events, from a meta perspective. Indeed, semiotics is a metadiscipline, transcending all those partial representations that are the focus of the object sciences. This confers upon semiotics an epistemological status different from that of particular sciences. That is, it is a “science of sciences” as Charles Morris [7] called it. Its generalizations in semiotic theory are not conducive to technological innovation as such, but rather guide the effort, such as in the design of user-computer interfaces, or the conception of languages, such as those used for programming or those based on the DNA code. However, semiotic generalizations are extremely effective at helping specialized research to maintain a reference outside the specialization pursued. They help scientists realize the relation between what is represented – in our case, Xevents (the representation), in whatever scientific theory and by whichever means, including mathematical formulae and computer programs – and the interpretation process associated with it. When many disciplinary and societal views are produced, which is certainly the case for this book and for which my contribution is conceived, we realize the need for a comprehensive transdisciplinary framework that can guide the individuals involved towards realizing the meaning of all of the specialized views and methods advanced. An effective framework for further research in Xevents ought to facilitate integration of knowledge, as well as the conception of new ways of disseminating knowledge, leading to decision-making and action.

The formalisms associated with semiotics are varied. They are of logical origin. In the late 1970s, I worked on a mathematical formulation of semiotic operations [8]. Animated by his interest in Peirce’s sign classes, Robert Marty [9–11] pursued a similar goal. Joseph Goguen [12] finally worked towards the explicit goal of an algebraic semiotics, facilitating applied work. Neither of us considered that the study of Xevents might benefit from semiotics, formalized or not. But in the final analysis, what brought up the semiotic perspective in these introductory lines was the broad motivation of our effort: how to make semiotics useful beyond the contemplative dimension of every theory. One avenue, as it now turns out, is the path towards the foundation of anticipation, the anticipation of Xevents, in particular.

2.2 From Signs to Anticipation

Let me quote from the Introduction to the Report of the workshop entitled *Extreme Events: Developing a Research Agenda for the 21st Century* [13]:

It is no overstatement to suggest that humanity's future will be shaped by its capacity to *anticipate* [italics are mine], prepare for, respond to, and, when possible, even prevent Xevents.

The notions of anticipation and of the sign are coextensive. Representations come into existence as the living – from the simplest level (monocell) to the most complex known to us (the human being) – act. Vittorio Gallese [14] brings proof that acting and perceiving cannot be effectively distinguished. He starts with an obvious example: the difficult task of reducing one's heartbeat is made easier once a representation – an electrocardiogram in real time – is made available to the subject. Indeed, biofeedback provides an efficient way of controlling a given variable (heart rhythm in the example mentioned, see [14]).

Representations, which are the subject of semiotics, are relational instruments. Every human action – and for that matter, every action in what is called the living – is goal driven. Gallese reports on single-neuron recordings in the premotor cortex of behaving monkeys. What drives the neurons is the goal of the action. He states:

To observe objects is therefore equivalent to automatically evoking the most suitable motor program required to interact with them. Looking at objects means to unconsciously 'simulate' a potential action. In other words, the object representation is transiently integrated with the action-simulation [14].

Quite some time before Gallese's experiments, my own elaborations [15] on what drives the human being – the actions through which they self-constitute; their pragmatics (we are what we do, no more, no less) – reached a point that is the fundamental thesis of this article.

Thesis 1. *Xevents should be qualified in relation to how they affect human life and work.*

Let me explain: Xevents, regardless of their specific nature, are not simply acknowledged by virtue of their syntax (the formal characteristics as we read them on various recordings of seismic activity, brain activity, wind direction and intensity, and so on). Xevents are not reducible to the semantics defining them as such; the label applied in the form of a category of hurricane, or assigned seismic intensity on a standardized scale, or a seizure type, for example. The defining quantifier regards how they affect human activity: the pragmatics of existence.

It is the dynamic relation between the event and those experiencing it (directly or through some form of mediation) that counts. Moreover, the plurality of relations, corresponding to the various ways in which we interact with the world in which we constitute our identity, is what interests us. That we can quantify the effects of Xevents (in the number of lost lives, in the costs

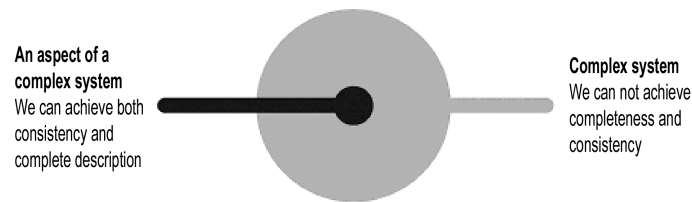


Fig. 2.2. Consistency and completeness are complementary. In order to circumvent the intrinsic characteristics of complex systems, we can focus on partitioned aspects. The challenge is to perform an adequate partitioning

of preparation, recovery, and damaged infrastructure, in ecological impact, and so on) does not mean that the numbers represent the impact of the event. Human life and activity are subject not only to quantity descriptions, but also to deep quality consequences.

What guides the exposition so far is the realization that while everyone wants to anticipate, or at least somehow, even in a limited way, to predict Xevents, we must remind ourselves of Gödel's warning [16], that we can at best expect partial results: a complex system cannot be described in both a complete and consistent manner at the same time. As a theorem in formal logic, it has often been misinterpreted. The reason we bring it up here is the methodological need to find out the extent to which it predicts the necessary failure of all attempts to anticipate Xevents, or whether it only suggests that we need to consider ways to segment or partition the various aspects of Xevents and concentrate on partial representations (see Fig. 2.2).

2.3 Descartes Rehabilitated

Seen from this perspective, Descartes' reductionism and determinism – the foundation of humankind's enormous scientific and technological progress in the last 400 years – makes more sense than his critics would like to credit him with. The question of whether Descartes knew well ahead of Gödel that complex systems are impossible to handle in their entirety, or whether he only asked himself (obviously in the jargon of the time) how to reduce complexity without compromising the entire effort of knowing will never be unequivocally answered. What we do know is that reductionism and determinism operate in a major section of perceived reality: everything there is (reality) is reduced to that subset of reality that constitutes the subject of physics. And everything that functions, including the living – minus the human being, for religious reasons that had more to do with Descartes' caution than with scientific reasoning – is seen as equivalent to a machine. That Descartes' understanding of the physical world and our current understanding of physics are quite different needs no elaboration. Science advanced our understanding

of determinism and causality in ways that at times appear to be counter-intuitive. Think of the quantum mechanical description of the microcosm. Think of the dynamic system models in which self-organization, among other dynamic characteristics, plays an important role in maintaining the system's coherence. Hence, it would be unwise not to distinguish between

1. Xevents in the realm of the physical world, for which the science inspired by the Cartesian model is, if not entirely adequate, the best we have.
2. Xevents in the living, for which the Cartesian perspective is only partially relevant.

2.4 Time, Clocks, Rhythms

If the representation of an Xevent as a representamen R were possible, it would necessarily involve a time dimension. After Descartes, time was associated with the simplest machine of his age – the pendulum clock – and reduced to an interval. If not Descartes, then at least some of his contemporaries already knew that to associate gravity with rhythm is convenient, but not unproblematic. At the poles (north or south), time in this embodiment is quite different from the time in Paris or in Dallas, Texas. And on a satellite, depending upon its orbit, it is a different time again. This problem was addressed by adopting oscillations (mechanical, as in clocks and watches, or atomic) and resonance as a “time machine”, and then declaring a standard – that of the cesium atom – which was easy to maintain and to reference. But with Einstein and relativity theory, we came to realize that the “atomic clock” is only a good reference as long as it is not subjected to a trip on a fast-moving carrier. Some physical phenomena take place along a timeline for which the day-and-night cycle in the western hemisphere, or the pendulum's gravity-driven rhythm, is either too fine-grained (think about cycles of millions of years), or too coarse (fast processes at nanoseconds and scales below this). Even more dramatic is our realization that many different clocks operate at the same time within the living, and many synchronization mechanisms are apparent. If they are affected, the system can undergo extreme changes. It turns out that the linear representation of time, through an irreversible vector, is a useful procedure so long as the time it describes is relatively uniform and scale-independent. But time is neither uniform nor independent of the frame of reference.

Once we ask what it would take for the representamen R of an Xevent to become a complete, effective description of the event, we implicitly ask what it would take to anticipate it. Indeed, a complete description can only be fully predictive if it makes a time difference mechanism possible:

Event (E) as a function of time t_E
 Prediction (P) as a function of time t_p

Evidently, the two times t_E and t_P are not identical: $t_E \neq t_P$. Moreover, t_P must be faster than t_E in order to allow for the possibility of prediction or anticipation.

An anticipatory system is a system whose current state depends not only on a previous state, but also on future states [17, 18]. In contrast to a predictive mechanism that infers probabilistically from the past, an anticipatory procedure integrates past experiences, but weighs them against possible future realizations. One of the better-known operative definitions of an anticipatory system is: “An anticipatory system is a system that contains a model of itself unfolding in faster than real time” [19]. What this description says is that simulations are the low end of anticipation. What it does not say is that although we can execute different operations (for instance, computations) in parallel within physical systems (machines, in particular), and even perform some operations (computations) faster than others, without a mechanism for interpreting the meaning of the difference between “real-time” operations (computation) and “faster than real-time” operations (computations), we still do not have an effective anticipatory mechanism. Indeed, only an understanding of the difference in outcome between so-called real-time and faster-than-real-time operations can afford anticipation. Two conditions must be fulfilled:

1. The effective model should be complete.
2. An effective mechanism for discrimination between the process and its model must be implemented.

Some would argue that the model does not have to be complete (or that it cannot be complete). If this were true, we might as well make the conception of the incomplete but still useful model the task of predicting, as though we knew which part of the dynamics of the system is more relevant than what is left out. Others argue that all it takes is some intelligence in order to understand the meaning of the difference. From all we know so far in dealing with anticipation and the human being, intelligence is marginal, if it plays any role at all. Let us discuss some classical examples.

Anticipation of moving stimuli (see Berry et al. [20]) is recorded in the form of spike trains of many ganglion cells in the retina. The facial action coding system (see Ekman and Friesen [21]) is a record of “character” that we spontaneously “read” as we perceive faces in some unusual situations (the trusting hand extended when there is need). Proactive understanding of surprising events is the result of associative cognitive activity (see Fletcher et al. [22]). More recently, Ishida and Sawada [23] confirmed that the hand motion precedes the target motion. (Remember when you last caught a falling object before you “saw” it?) Intelligence is not traceable in the process or in the quantitative observations. As a matter of fact, high performance anticipation, such as that seen in skiing, tennis, hockey and soccer, is not associated with a high IQ or with any other feature of intelligence. What is identifiable is learning (and implicitly the dimension of training anticipatory attributes)

although of a precise type. It is not explanatory learning; it is rather procedural, internalized rather than externalized.

In view of this, a representamen R of an Xevent understood as being its full operational description makes sense only in association with an interpretant process I . This itself can be conceived as a machine that is context-sensitive and able to learn. As the representamen unfolds in a neverending prediction sequence, the interpretant not only relates it to the Xevent it captured, but also to other events as they take place in the world. In order to achieve this dynamic behavior, it has to be conceived as a distributed computation; actually, as a grid process that takes as input the knowledge acquired so far (representamen) as well as the new knowledge resulting from the representation of Xevents taking place in real time. And even in this possible implementation, the interpretant process will not be more than a surrogate to a living interpretant process.

2.5 The Hybrid Solution

Thesis 2. *Since the living is not reducible to a machine, our best chance of understanding our own knowledge regarding Xevents, and thus provide for effective anticipation, are hybrid systems that integrate the human being.*

I am aware that this thesis runs counter to the dominant expectation of fully automated anticipation, or at least prediction. Although we deplore the enormous cost of the consequences of Xevents – often including death and bodily impairment, disease and suffering – we are, so it seems, not willing to take on board that the most expensive machinery imaginable today will not fully replace the interactions of minds (see Nadin [24] as a component of the interpretant process. Our obsession is still with the interaction (see Fig. 2.3) of the human – machine interface in particular.

This focus is not unjustified to the extent that we entertain the illusion that machines will eventually carry out any and every form of human activity. After all, Minsky [25] was not alone in stating that

In from three to eight years, we will have a machine with the general intelligence of an average human being. I mean a machine that will be able to read Shakespeare, grease a car, play office politics, tell a joke,

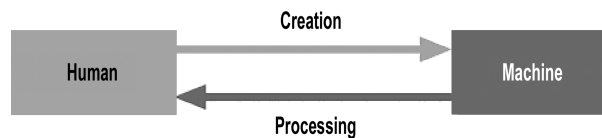


Fig. 2.3. Human–Machine interaction. The process is intensely asymmetric/asynchronous

have a fight. At that point, the machine will begin to educate itself with fantastic speed. In a few months, it will be at genius level, and a few months after that, its power will be incalculable.

Despite this reductionist-mechanistic viewpoint, we are now discovering that, given the continuous diversification of human activity, the machine is bound to be at least one step behind human discovery: it does not articulate questions. Expressed in other words, we are discovering new ways through which we can increase the efficiency of our efforts (physical, mental, emotional). Therefore, the logical alternative is not to transfer human functions and capabilities to machines, but to provide for an alternative model: the integration of the human being and the machine. What results is a very complex entity, ultimately characterized by its degree of integration. Instead of limiting ourselves to the Human–Machine interaction, we should concentrate on the very complex entity that results from integration (see Fig. 2.4).

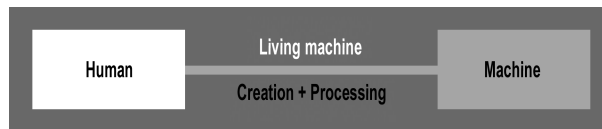


Fig. 2.4. The “Human–Machine” living machine

Let us contemplate simple examples of implementation:

1. The “mind” driving the machine (see the experiments, so far performed with monkeys [26]), which avoids the “bottleneck” of current user interfaces, which are notoriously asynchronous. We know that a lot comes out of machines, but very little – mainly interrupt commands – pass from the user to the machine.
2. The coupling of the nondeterministic “state-of-the-human” informational space (containing many parameters, with heterogenous data types such as temperature, color, pressure, rhythm, and so on) with the deterministic machine state, such as in hybrid control mechanisms. The data bus in the machine part is connected to the “living bus”; rich learning and forgetting affect interactions between the human and the machine.

These examples reflect the “state of the art” currently reached. If we could further integrate the living (not only human) and a machine endowed with pseudo-living properties (such as evolutionary programs), we would be better positioned to achieve a semiotic machine in the proper sense of the expression, and thus we might expect anticipatory characteristics augmented by computation.

Let us revisit the introductory hypothesis: the possibility of achieving a full record of an Xevent. We denoted the Xevent as object O without considering its condition. In reality, an Xevent appears to us – as we are part

of it, experiencing it – as an immediate object: the meteorologist is inundated with data from trackers, radar readings, and sensor information. (Similar readings are made by a physician examining a patient who might have an epileptic seizure; or by seismologists as they consider issuing a warning of a catastrophic earthquake that would require massive emergency measures.) The immediate object O_i , which can be characterized through rich data, is only suggestive, but not fully indicative, of the dynamic object. After all, the tornado might not take place, despite all the readings; the seizure might not occur, or might take a mild form, indistinguishable from normal brain activity; or the seismic wave might be ambiguous.

Associated with the immediate object O_i is the immediate, although at times less than precise, understanding of what the description (representamen) conveys (the immediate interpretant I_i). In what we all we call prediction (including forecasts), most of the time this understanding is based on previous experience, that is, on probabilities. For example, in the past, a radar echo and a triple point on a surface chart suggested tornados. The dynamic interpretant I_d , not unlike a neural network propagation, corresponds to inferences from what is apparent to what might happen – to the space of possibilities. This consists of all that can happen (events associated with meteorology data such as weak shear, moisture, stationary front in vicinity). Integrating the probabilistic and the possibilistic dimensions of Xevent forecast is the final interpretant I_f : “If you haven’t thought about it before it develops, you probably won’t recognize it when it does”. This comes from a professional in weather forecasting, Charles A. Doswell, III, as reported by Quoetone and Huckabee [27]. The transcripts of the various conversations among traffic controllers, airline representatives, and the military personnel in charge of guarding USA air space during the events surrounding the terrorist attacks of what has come to be known as 9/11 clearly reveal that nobody thought about the possibility of an operation at the scale of and with the means conceived of by the terrorists. The diagram given below captures the intricate relation (corresponding to a triadic-trichotomic sign relation) of the entities under consideration:

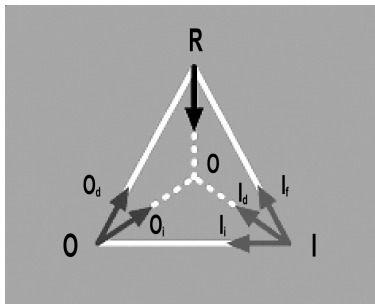


Fig. 2.5. The triadic-trichotomic sign relation

It is no accident that the infatuation with the sign originates in medicine; more precisely, in the practical endeavor known as diagnostics. But the “symptoms” of Xevents (also known as foretelling signals, whether in seismology, meteorology, medicine, terrorist activity, market analysis, and so on) point to a very complex sign process. The triadic-trichotomic representation of the sign suggests the need to distinguish between the appearance (immediate object O_i) and the evolving object of our attention (dynamic object O_d). It also makes us aware that the process of interpretation starts with the perception of appearance (I_i) and continues with the formulation of a theory (I_f), which in turn can be further interpreted (the state of knowledge regarding an Xevent at some moment in time). Quite often, we examine a representamen R as a symptom (for instance a seismogram, or some representative data pertinent to physical events) and infer from symptoms to possibilities, that is, a quantified record of what can be expected.

Xevents are notorious for casting doubt on forecast verification statistics. Due to the nonlinearities characteristic of Xevents, random factors lead to an ever-increasing difference between the statistically driven prediction and the observed event. Combining probabilistic and possibilistic descriptions allows new modeling perspectives. The fact that probability and possibility are not independent of each other (nothing can be probable unless it is possible, and not every possibility can be associated with a probability before an event) makes the task even more difficult. Since a vast body of literature on probability is available, I will make only a brief reference to possibility distributions.

Actually, we know that there is no “generally accepted formula for the mean of uncertainty or ignorance induced by a possibility distribution” [28]. The best that, to my knowledge, has been proposed so far is an E -possibilistic entropy measure. If $\Lambda = \alpha_1, \dots, \alpha_k$ is a set of outcomes (for example the effects of an earthquake, or of a storm), and $\Pi = \pi_1, \dots, \pi_k$ is a possibility distribution (with $\pi_i = 1, i = 1, \dots, k$), the measure of uncertainty (or ignorance) is the optimal value of the nonlinear equation:

$$\max H(p) = - \sum_{i=1}^k p_i \log p_i \quad (2.1)$$

subject to the limitations:

$$\sum_{i=1}^k p_i = 1, \quad \sum_{i=1}^k \pi_i p_i \geq \varepsilon, \quad \text{and} \quad p_i \geq 0.$$

Indeed, we are always informed, at least partially, about what has already happened; but we are ignorant in respect to what might happen (the possible event). The measure of our ignorance is always dependent on how well defined the possibility space is. The consequences for which α_i stands are hypothetical, and are sometimes (such as in financial crashes) affected

by the perception of those involved (the investors), but are usually not obviously dependent upon their activities. A house constructed in the vicinity of a fault-line does not augment the intensity of the earthquake (should one take place) but it does affect the impact (human, social, economic, and so on). The possibility distribution is therefore a representation of the various correlations expressed in the Xevent. Possibilistic entropy does not depend only on the possibility distribution. Together with probability considerations, these intricate relations are implicit in the R expression and are indicative of Xevents both in the physical and in the living.

We ought to note that these entities (R, O, I) are not abstractions, but a logical guide to constructing an effective system of anticipation. Accordingly, we need to proceed by giving life to this diagram, such as by specifying the relation between the data and the possibility distribution. We also need to define all of its components, and furthermore, to proceed with a semiotic calculus that will generate an anticipatory self-mapping system. To give just one example, let us define an Xevent as an expression of dynamics. (“Expression” is used here in analogy to gene expression.) If we accumulate data (such as meteorological, geological, brain activity, financial market transactions; each associated with a possible Xevent) our goal would be to extract R patterns of expression (patterns of dynamics, or patterns of change) inherent in the data from the representamen. Mathematical techniques for identifying underlying patterns in complex data (in complex representamina) have already been developed for object recognition by computer-supported vision systems, for phoneme identification in speech processing, for bandwidth compression in electrocardiography and sleep research. These are clustering techniques (hierarchical, Bayesian, possibilistic, and so on). Among these techniques, so-called self-organizing maps [38] can be defined to correspond to a semiotic self-mapping. Such maps use visualization techniques to reduce the data space with the help of self-organizing neural networks. In effect, similarities in the data are evidenced by grouping similar data items. This involves a high number of iterations. In the final analysis, an SOM is associated with a grid. The rectangular grid used is somewhat analogous to an entomologist’s drawer (adjacent compartments hold similar insects), although I actually prefer the analogy to a philatelic collection (adjacent pages in the album hold similar stamps or series). The SOM of a possible Xevent is a representation of all the “insects” or “stamps” not yet collected, or the “stamps” not yet printed. For an iteration i , the position of a variable V_e is denoted $f_i(V_E)$. The formula

$$f_{i+1}(V_E) = f_i(V_E) + \tau(d(V_e, V_{EP})I)(P - f_i(V_E)) \quad (2.2)$$

describes the next position of the Xevent variable considered. Notice that the position corresponding to possible data point P (which is a node V_{EP} in the grid) and the variable V_e are subject to a distance evaluation $d(V_e, V_{EP})$. Learning is involved in the process (τ is the learning rate); the learning rate decreases as the distance between V_e and V_{EP} decreases. Indeed, if the difference tends to zero between the possible value and the observed value, there is

nothing left to learn. There is randomness, accounted for in order to replace the living component. In such a procedure, semiotic considerations are no longer meta-statements, but become operational.

Human beings operate naturally in the semiotic realm. They generate cognitive maps as they act in relation to the Xevent variable. These mental maps guide our actions. Even the influence of predictions and forecasts affect these self-generated maps. We do not process chairs or electrons or thunder in our minds, but rather their representamina. Accordingly, a semiotic machine combines the perception of signs with the production of signs (see Fig. 2.6):

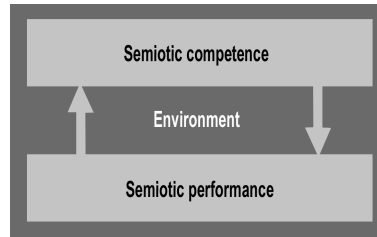


Fig. 2.6. The unity of action and perception

What the diagram suggests is that the human being's self-constitution (how we become what we are through what we do) implies the unity of action – driving our perception of the world – and reflection. Therefore, to do something, such as to deal with Xevents – reflect upon them, cope with their impact, predict them – actually means to anticipate the consequences of our actions. In effect, this translates neither into an anticipation method nor into specific means, but rather into the realization that anticipation is an evolution-immanent characteristic. Should we ever be able to build an evolutionary machine (to create a living entity), it will have to display anticipatory characteristics. For all it's worth, the realization that anticipation is an evolution-immanent characteristic means that anticipation of Xevents is possible, but not guaranteed. Evolution itself is not a contract with nature for individual survival or survival of the species. The Xevent that led to the extinction of the dinosaurs is only one example among many others.

If instead of considering the R of a natural Xevent (an earthquake and the like) we look at the plans on whose basis the A -bomb was built, or on which chemical and biological weapons are produced, or the new “smart” weapons (producing targeted Xevents!), we still remain in the semiotic realm. The R_A (for atomic bomb), or the R_C (for some chemical weapon), or the R_B (for biological weapons), or the R_S (for smart weapons) are an effective description of a potential Xevent, which we can fully predict within an acceptable margin of error. Bombing the desert (which used to be called nuclear testing) is quite different from bombing a populated area. We can also, within other margins of error, predict what might happen with respect to R_C or R_B , and even R_S .

The Xevent (O) – the unity between O_i and O_d , or the appearance and the dynamic unfolding of the event – contained in the description (R) becomes subject to a process of interpretation. This extends from scientific analysis and planning, to engineering and testing, as well as to media reports, fiction, and movies, not to mention the production of interpretations, true and false, of secret services intent on confusing the potential users of such devices. Indeed, Xevents, whether natural or artificial, become part of the political experience, and thus their prediction also impacts politics. Xevents lead to a whole bureaucracy (emergency funds set up to meet needs), and to new laws (including ones intended to prevent market crashes or terrorist attacks).

It has often been remarked that social systems (and for that matter, systems pertinent to living communities, human or not) display anticipation. The less constrained a system is, the higher its resiliency. Meaning comes into existence with hindsight: “What happened to the subway that came to a screeching halt? What does it mean that an airplane hit a skyscraper? What does it mean that someone has a seizure?” A logistic map can inform us about a direction of change. Market processes exemplify the process. Feedback and feedforward work together; production, supply, demand, and all other factors are underlying factors in market dynamics. A crash – an Xevent – is not dependent upon the anticipatory actions of informed or uninformed individuals, but rather upon aggregate behavior. Cellular automata able to operate on two different timescales (real time vs. faster than real time) could, in principle, capture the recursive nature of those who make up the market.

But in real life (whatever that means), we can only act in the present (as events are triggered). As such, the interpretant process for which a cellular automaton stands appears as a funnel to us:

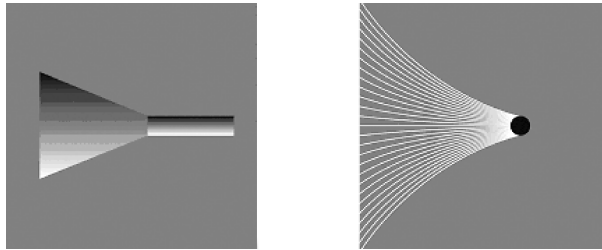


Fig. 2.7. An Xevent as a realization in a possibilistic space along a time axis

The immediate object (the Xevent) unfolds in the huge space of possibilities that one can conceive of and pursue systematically. To be successfully anticipatory means to progressively reduce this space until the convergence of the open cone-shaped object.

2.6 Can a Computer Simulate Anticipation?

In effect, to anticipate is to move along the time vector from the event (tornado, flood, seizure . . .) – the neck of the funnel – as it unfolds, to its initial conditions. In the language of dynamic systems, this means to move from the strange attractors embodying the Xevent to the conditions feeding the dynamics of the system. Nonlinear processes affect the “edges” of the dynamic distribution (for example: how wide a swing a stock market can take, what the most extreme temperatures are, what the atmospheric pressure values are, what the seismic parameters are, the level at which a system’s stability is affected). But there is no indication whatsoever that these processes display any regularity.

Scientists such as Sornette, Helbing, and Lehnertz – to name three among those published in this volume – are dedicated to this approach. For instance, Sornette is well respected for considering self-organized criticality and out-of-equilibrium conditions. He advanced the hypothesis that Xevents are due to the system’s endogenous self-organization. In contrast to prevailing views, he covers a very large area of public interest (from geological aspects to the future of humankind on earth). The abstraction in Helbing’s model of collective behavior goes back to self-driven many-particle systems. Malfunctions in the form of abnormal synchronization of a large number of neurons catch the attention of those (such as Lehnertz) looking for the prediction potential of apparati (such as multichannel EEC recorders), if an appropriate determination of the abnormality, detected through statistical evaluation, is performed.

Each time they, and others who follow a similar physics-driven path to discovery, come upon patterns in the data subject to their examinations, they pursue the thought of identifying regularities that can ultimately justify prediction. Some are on record – a very courageous scientific attitude – with predictions (regarding, say, the economy, financial markets) that the public can evaluate. Others have commercialized their observations (for example on crowd behavior). It would be out of character and out of the question for me to cast doubt on models mentioned here for their elegance and innovation. But the reader already knows where I stand epistemologically. And given this stand, I can only suggest that, for the particular aspects on which my colleagues focus, acceptable predictions are possible. What is not possible is a good discrimination procedure, one that allows us to compare, ahead of the

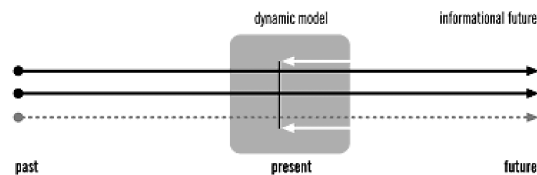


Fig. 2.8. A model unfolding in faster than real time appears to the observer as an informational future

future, between good and bad, appropriate and inappropriate predictions. For the past, which they assume to be repeated in some form or shape, the prediction is usually good (or at least acceptable). But once complexities increase, even within the physical, the Xevent starts to look like a “living” monster. We cannot afford to ignore this fact.

This journey from the Xevent states to the states leading to it is, for all practical purposes, a reverse computation (regardless of whether the computer is implemented in silicon, DNA, quantum states, and so on). In Richard Feynman’s words [29], this is equivalent to asking, “Can a computer simulate physics exactly?” Reversibility is in fact the characteristic of a computation in which each step can be executed and unexecuted. Making and unmaking an omelette is one way of suggesting what we are referring to here. Increase this to the scale of an earthquake and imagine the weird computation of the earthquake as output, and its reverse. But even at the scale of an epileptic seizure or financial crash, the film played in reverse is not easy to conceptualize – and it is not at all clear whether it is feasible.

That physical laws are generally reversible automatically allows for a reversible computer (with all of the costs associated with the erasure of information). But what is not clear is whether an earthquake, a heart attack, a tornado, or a seizure is the result of a deterministic process, or at least one of deeper levels of order. If the computation of an earthquake involved the condition of the process leading to the earthquake – that is, if one could define an “earthquake machine” – we would probably profit from the reversibility of the computation. It is very exciting to compute in the medium we examine, provided that we examine events of a regular nature (no matter how deep the regularity is hidden). But, not unlike the infinite interpretant process characteristic of semiotics (each interpretation becomes a new sign, *ad infinitum*), Xevents seem either unique (irreducible to anything else) or only an instance of a longer development that goes beyond what we call tractable.

2.7 A New Equilibrium

Thesis 3. *Xevents are actually the preliminary phase leading to a necessary new state of balance leading to the next Xevent (see Fig. 2.9).*

What I am saying here is that the epileptic seizure is, in its own way, a process that preserves life, since it leads to the post-seizure condition that replaces the endangering state prior to it. Or, that the earthquake – a tremendously energetic peak – ends up in the post-quake condition of relatively energetic balance, and of infinitely less destructive potential earthquake. Otherwise, the potential future event would grow and grow until the earthquake’s resources are exhausted. With this in mind, I suggest here that we are dealing with what physics has stubbornly rejected for the sake of homogeneity and determinism: the *causa finalis* as the necessary path of dynamic unfolding.

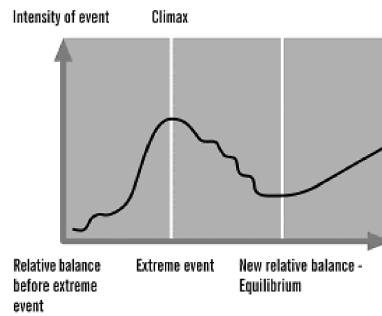


Fig. 2.9. The relevance of the post-extreme event time

Aristotle distinguished among four categories of causation: material cause, formal cause, efficient cause, and final cause. In contemporary jargon, they correspond to different kinds of information. If we apply these categories to a house, it is evident that materials – cement, brick, wood, nails – pertain to the material cause. Builders (think about the many types of workers involved in excavating, mixing and pouring concrete, bricklaying, and so on) make the efficient cause clear through their work, while the plans they go by (blueprints and various regulations) represent the formal cause. The final cause is clear and simple: someone needs or wants to live in such an edifice.

Now take a work of art. The materials, the work of an artist, and the various sketches are well defined. But who needed or wanted the work? (Who needs or wants an Xevent?) In some cases, there is one person who acted as commissioner. In the majority of cases, the action (make the artwork) is driven by the artist dedicated to expressing himself or herself, to ascertaining a view or perspective, to unveiling an aspect of reality unknown to others or perceived in a non-artistic way. The final cause is the work itself, as it justifies itself within a culture and within a social context. The pragmatics of art is the answer to the “Why?” of a work of art, not to the “How?” (which pertains to its efficient cause). As science eliminated the legitimacy of anything even slightly related to *causa finalis*, it raised the infatuation with “How?” to the detriment of the question essential to any artistic experience: “Why?” Indeed, the “Why?” of an Xevent should interest us at least as much as the “How?” if we want to get closer to the prediction, and to the anticipation of Xevents.

It is less suspicious to affirm such an idea today now that bifurcations and attractors were introduced into scientific jargon (see Feigenbaum et al. [30]). The equilibrium following Xevents makes us aware of the variety of ways in which the physical substratum of everything is preserved through infinite processes. However – and this goes back to the major distinction I have advanced so far – Xevents in the physical universe compared to Xevents in the living are subject to predictive actions only to the extent that a pre- and a post-phase are identifiable. In this sense, time appears as a component of life, not just as one of its descriptions.

This prompts the next thesis of this article.

Thesis 4. *The action of anticipation cannot be distinguished from the perception of the anticipated.*

This applies in particular to Xevents as episodes in the self-constitution of the living, of the human being in particular. Testimony from folklore and anthropological evidence make us aware of the variety of anticipatory behaviors of the living (animals, insects, reptiles, plants, bacteria) in relation to Xevents. This evidence has always been subjected to scientific scrutiny: can it be that in some cultures important information regarding Xevents (earthquakes, floods, seizures, epidemics) has been derived through the interpretation of animal behavior and characteristics by the people sharing the environment with them? And if so, can we derive anything useful for predictions of Xevents from this information? After all, the living is endowed with anticipation, and accordingly, the anticipation of Xevents in the natural realm cannot be excluded. Moreover, there is sufficient anecdotal evidence to suggest that epileptic seizures in humans are signaled ahead of time by dogs. Similar anecdotal reports are often mentioned, even in scientific publications.

As non-natural factors – such as anthropogenic forces related to urban development, land conversion, water diversion, pollution – increasingly affect the environment, animals, birds and plants exhibit new patterns of behavior. Even these changes are indicative of the tight connection between all of the components of the ecosphere. Ecological consequences of Xevents are rapidly becoming the focus of many scientists who realize the need for a holistic approach (such as the British Ecological Society [31]). We are losing important sources of information as we create artificial circumstances for nonlinearities that, instead of eliminating the risks associated with Xevents, actually increase their impact, and sometimes their probability and possibility. Numerous dams that only marginally adequately function under extreme weather conditions have made us aware of the Xevent potential their failure can entail. Buildings of all types, devices we place on mountains or under water, satellites circling the earth – these have all amplified the possibility space of Xevents. The possibility of hitting skyscrapers with airplanes did not exist before we started to fly using “mechanical birds”, and built them high into the sky. In this context, interestingly enough, we are forcing nature (and ourselves) towards machine behavior. Farms become food factories; workers are expected to act like machines; institutions become machines with specialized functions (doctors are human body mechanics, hospitals are spare parts factories, the state is a machine for maintaining the coherence of the social system, the police are machines for maintaining order). The expectation is regularity, and all the measures undertaken worldwide following 9/11 are meant to maximize the predictability of the irregular (including the Xevents subject to the scrutiny of Homeland Security).

This expectation is fed by a scientific model of prediction and reproducibility corresponding to the world of physics. Indeed, dropping a stone

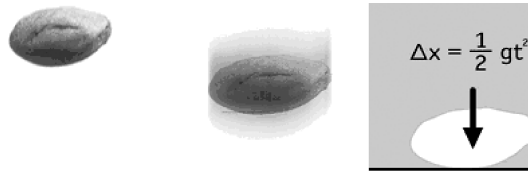


Fig. 2.10. Given the same conditions, a stone will fall the same way

from the same position, under the same circumstances (humidity, wind) will always result in the same measurements (of speed, position at any moment in time, impact upon landing). It is a predictable experiment; it is reproducible. Even if we change the topology of the landing surface, the outcome does not change.

Let a cat fall and derive the pertinent knowledge from the experiment. This is no longer a reproducible event. The outcome varies a great deal, not the least from one hour to another, or if the landing topology changes. The stone will never get tired, annoyed, or excited by the exercise.

Applied differential geometry allows for the approximate description of an object flipping itself right side up, even though its angular momentum is zero. In order to accomplish this, it changes shape (no stone changes shape in the air). In terms of gauge theory, the shape-space of a principal $SO(3)$ -bundle, and the statement “angular momentum equals zero” defines a connection on this bundle [32]. The particular movement of paws and tail conserves the zero angular momentum. The final upright state has the same value. This is the “geometric phase effect”, or monodromy. Heisenberg’s [33] mathematics suggests that, although such descriptions are particularly accurate, we are, in observing the falling of a cat, not isolated viewers, but coproducers of the event. The coherence of the process, not unlike the coherence of the apparently incoherent class of events we call extreme, is the major characteristic.

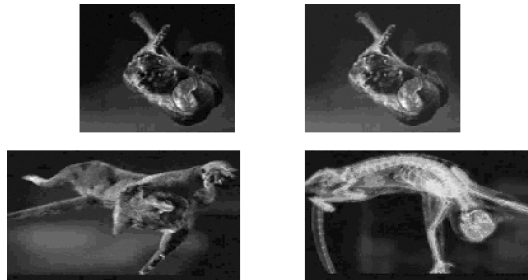


Fig. 2.11. The cat never falls the same way

This is where the need to consider the living as different from the inanimate physical becomes more obvious. In order to address this, I will make

reference to the work of an established physicist, Walter Elsasser, who worked in quantum mechanics (with Niels Bohr) and was very familiar with Heisenberg. He dedicated the second part of his academic career to a scientific foundation of biology. These considerations are appropriate in this context if the fundamental distinction between Xevents that are physical in nature and Xevents that are peculiar to the living are to be pursued effectively. They can guide us further if we realize that there is more than a one-way interaction between Xevents, as they emerge, and our perception. We are not just spectators at a performance (sometimes scary), but also, in many ways, coproducers.

2.8 A Holistic View

A physicist of distinguished reputation, Walter Elsasser [34] became very interested in the living from an epistemological perspective. As in Rosen's case – Rosen being the mathematician most dedicated to the attempt to understand what life is – it would be an illusion at best to think that we could satisfactorily summarize Elsasser's attempt to reconcile physics with what he correctly perceived as a necessary theory of organisms. Rosen and Elsasser had a focus on complexity in common. But in contrast to Rosen, Elsasser was willing to pay his dues to the scientific matrix within which he found his own way: "The successful modern advance of reductionism rests on certain presuppositions which at this time are no longer questioned by any serious scientist". Moreover, and here I quote again, "There is no evidence whatever that the laws of quantum mechanics are ever wrong or stand in need of modification when applied to living organisms". All this sounds quite dogmatic and, for those versed in science theory, almost trivial given the fact that theories are ultimately coherent cognitive constructs, not continents waiting to be discovered. Physics, in its succeeding expressions, is no exception. For the reader not willing to delve into the depths of the argument, the position mentioned is not really inspiring. Opportunistically, and as Rosen did too, he refutes vitalism, "the idea that the laws of nature [that is, physics] need to be modified in organisms as compared to inanimate nature". Serious scientists in all fields and of all orientations have discarded vitalism, just as alchemy was discarded centuries before. After all these preliminaries, Elsasser finally articulated a clear point of departure for his own scientific journey, which justifies continued interest in his work: "Close reasoning indicates the existence of an alternative to reductionism. This is so despite the fact that the laws of quantum mechanics are never violated".

From this point on, we have quite an exciting journey ahead of us. Indeed, biology is a "non-Cartesian science". The "master concept" in describing the holistic properties of the living is complexity [34]; more precisely, what he describes as unfathomable complexity. This concept dominates the entire endeavor; therefore an extended quotation is probably justified. Unfathomable

complexity “implies that there is no series of actual experiments, and not even a set of suitably realistic thought-experiments such that it would be possible to demonstrate the way which all the properties of an organism . . . can be reduced to consequences of molecular structure and dynamics . . .”. Furthermore, he defines properties those that remain unaccounted for by physics and chemistry as morphological. Four principles and a “basic assumption” stand at the foundation of his biology. The assumption refers to the holistic view adopted – the living cannot be understood and described other than as a whole: “the organism is a source (or sometimes a sink) of causal chains which cannot be traced beyond a terminal point”; that is, they are ultimately expressed in the unfathomable complexity of the organism.

According to this viewpoint, Xevents in the living cannot be meaningfully addressed on the basis of reductionism (not even at the level of detail of single neuron functions or genetic expression), but only globally, in a holistic manner.

The first principle that Elsasser further articulates is known as *ordered heterogeneity*. It states that, as opposed to the homogenous nature of physical and chemical entities (all electrons are the same), the living consists of structurally different cells. There is order at the cellular level, and heterogeneity at the molecular level. Heterogeneity corresponds to individuality, a term that has no meaning in the physical world. The principle of creative selection focuses on the richness of living forms. For homogenous systems, the variation of structure (if there is such a variation) averages out. For heterogenous systems (the living), an immense multitude of possible states is open to realization (selection). The property of selection is attributed to matter alone – a more refined mathematics of dynamic systems, which to date has not been formulated, would probably define some specific self-organizing action here. The selection as such is based on the third principle, of holistic memory. The new morphological pattern actually selected resembles earlier patterns, but is not the realization of stored information. Elsasser is quite convincing in arguing for a “memory without storage – the touchstone of the theoretical scheme proposed” [34]. The argument is based on the distinction between two processes: homogenous replication (the assembly of identical DNA molecules) and heterogenous reproduction (self-generation of similar though distinct forms). Always different, the living practice creativity as a *modus vivendi*. Replication is a “dynamic process” [34] resulting in what we perceive as regularities in the realm of the living. Replication and reproduction need to be conceived together. What makes this possible is the fourth principle, of *operative symbolism*. The discrete, genetic message is represented by a symbol that stands for the integrated reproductive process. Elsasser himself realized that this operative symbolism is merely a *tag* for all processes through which the living experiences its own dynamics. He looked for a triggering element, a *releaser*, as he called it, that could start a restructuring process. From a piece of genetic code, the releaser will trigger the generation of the complete message

necessary for the reconstruction of a new organism. We can imagine this releaser – the operative symbol – as able to start a “program” that will result in a new biological form, as an alternative to storing and transmitting the form itself. The biological information is stored as data (in the homogenous replication) and as an immense number of alternate states from which one will eventually be realized (in the heterogeneous reproduction). This latter assumption implies that biological phenomena are “in part” autonomous.

Again, when studying Xevents in the living – to which not only epileptic seizures and strokes belong, but also cancer and heart attacks – these observations are a good guide for prevention and anticipation. That earthquakes and hurricanes are always different, as are strokes and financial market crashes, speaks for the adoption of the over-arching notion of heterogenous replication.

Instead of searching for laws, Elsasser highlights regularities. Where reductionists would expect that “the gametes contain *all* the information required to build a new adult”, a non-reductionist biology would rely on holistic memory and his *Rule* of repetition: “Holistic information transfer involves . . . the reproduction of states or processes that have existed previously in the individual or species as the case may be” [34]. Of special interest to him is the re-evaluation of the meaning of the Second Law of Thermodynamics (and the associated Shannon law of information loss). Elsasser argued that since paleontology produced data proving the stability of the species (over many millions of years of existence), and since the Second Law of Thermodynamics points in the opposite direction, only a different integration of both these perspectives can allow us to understand the nature of the living. Therefore, two types of order were introduced, in a way such that they never contradict each other. This is what he called biological duality: “living things can be described by a different theory as compared to inanimate ones”. As a consequence, if one attempted to verify holistic properties, a different kind of experiment from the one conventionally used in physics would be required. It is worth mentioning here that Wilhelm Windelband [35] made the distinction between nomothetic and idiographic sciences. The latter focused on singularity: “der Gegensatz des Immergleichen und des Einmaligen”, (the contradiction of the invariable/unchanging and the unique).

It is at this juncture that Rosen’s thinking and Elsasser’s meet – I doubt that they had a chance to study each other’s work on the living and life in depth. Rosen was “entirely dedicated to the idea that modeling is the essence of science” [36]; Elsasser realized that no experiment, in the sense of experiments in physics, could capture the holistic nature of the living. Moreover, both asked the fundamental question: what does it take to make an organism? If the representamen R for an organism (such as the stem cell) were available, we would be able to anticipate Xevents in the living in relation to the end of life (return to physicality). But Xevents can also be viewed from the perspective of the same question: what does it take to make an earthquake?

Or an act of terrorism? Elsasser, not unlike Rosen, concluded: “The synthesis of life in vitro encounters insuperable difficulties” [34]. It is quite possible that such a strong statement corresponds to the realization that anticipation, as the final characteristic of the living, might be very difficult to describe (the analytic step) but probably impossible to reproduce (the synthesis). So, we might even be able to say what it takes to create a certain Xevent, but that does not mean that we could literally make it. Even induced seizures are not exactly like the ones experienced by individuals who go through real seizures. Low-scale earthquakes (caused by experiments and tests that researchers conduct) are by their nature on a different scale and quality than the ones that people experience on the Islands of Japan, in California, in China, or in Turkey. It is therefore of particular interest to take a closer look at the various factors involved in what, from a holistic perspective, appears to us as anticipatory.

We learn from this that there is no anticipation in the realm of physics. Accordingly, if we are dedicated to addressing Xevents – whether in the physical world or in the realm of the living (birth and death are themselves Xevents) – we need to realize that answers to what preoccupies us will result from understanding how the living anticipates. (We know why, since this results from the dynamics of evolution.)

The final thesis of this article is of less significance to prediction of Xevents and more to our anticipatory condition in the universe.

Thesis 5. *The project of extreme scientific ambition, of creating life from the physical, can succeed only to the extent that a physical substratum can be endowed with anticipatory characteristics.*

This conclusion is not a conjecture; it is strongly related to a better understanding of Xevents. It ascertains that in addressing questions pertinent to Xevents, we are bound to address (differently to Rosen) the notion of what life is. After all, nothing is extreme and nothing is an event unless it pertains to life.

References

1. Heraclitus, as mentioned in Plato: *Cratylus*, 402A
2. Peirce, C.S.: “Indeed, representation necessarily involves a genuine triad. For it involves a sign, or representamen, of some kind, inward or outward, mediating between an object and an interpreting thought. . .”. *The Logic of Mathematics* (1896). In: Hartshorne, C., Weiss, P., eds., *Collected Papers of Charles Sanders Peirce*, Harvard University Press, Cambridge, MA (1931), pp 1–480
3. Peirce, C.S.: “A sign is something which stands for another thing to a mind.” In: *Of Logic as a Study of Signs*, MS 380 (1873). See also: *The Writings of Charles S. Peirce*, Volume 3, 1872-1878, pp. 82–83. Peirce Edition Project, Christiane S.W. Kloesel et al, Eds. Bloomington IN: Indiana University Press, 1998

4. Peirce, C.S.: “Anything which determines something else (its interpretant) to refer to an object to which itself refers (its object) in the same way, the interpretant becoming in turn a sign, and so on ad infinitum” (1902). In: Hartshorne, C., Weiss, P., eds., *Collected Papers of Charles Sanders Peirce*, Harvard University Press, Cambridge, MA (1931), pp 2–303
5. Peirce, C.S.: “A sign is intended to correspond to a real thing.” In: *Foundations of Mathematics*, MS 9 (1903) 76 Definitions of the Sign by C.S. Peirce, researched and collected by Robert Marty. cf. <http://members.door.net/arisbe/menu/library/rsources/76defs/76defs.htm>
6. Schneiderman, B.: *Designing the User Interface*, Addison Wesley, Boston, MA (1998), p. 185
7. Morris, C.: *Foundations of the Theory of Signs*, In: Neurath, O., ed., *International Encyclopedia of Unified Science*, vol. 1, no. 2, University of Chicago Press, Chicago, IL (1938)
8. Nadin, M.: *Zeichen und Wert*, Gunter Narr Verlag, Tübingen (1981)
9. Marty, R.: *Catégories et foncteurs en sémiotique*, Semiotica 6, Agis Verlag, Baden-Baden (1977), pp 5–15
10. Marty, R.: *Une formalisation de la sémiotique de C.S. Peirce à l’aide de la théorie de catégories*, Ars Semeiotica, vol. II, no. 3, John Benjamins BV, Amsterdam (1977), pp 275–294
11. Marty, R.: *L’algebre des signes*, A John Benjamins, Amsterdam (1990)
12. Goguen, J.: *Algebraic Semiotics Homepage* (see <http://www.cs.ucsd.edu/users/goguen/projs/semio.html>), last accessed August 2005
13. NSF/CSPO/NCAR, *Extreme Events: Developing a Research Agenda for the 21st Century*, conference sponsored by the National Science Foundation (NSF), organized by the Center for Science, Policy, and Outcomes (CSPO) at Columbia University and the Environmental and Societal Impacts Group of the National Center for Atmospheric Research (NCAR), Boulder, CO, 7–9 June (2000)
14. Gallese, V.: *The Inner Sense of Action. Agency and Motor Representation*, In: *Journal of Consciousness Studies* 7, vol. 10 (2000), pp 23–40
15. Nadin, M.: *The Civilization of Illiteracy*, Dresden University Press, Dresden (1997)
16. Gödel, K.: *Über formal unentscheidbare sätze der Principia mathematica und verwandter systeme*. In: *Monatshefte für Mathematik und Physik*, 38 (1931), pp 173–198; translated in van Heijenoort, *From Frege to Gödel*, Harvard University Press, Cambridge (1971). The exact wording of his first theorem is “In any consistent formalization of mathematics that is sufficiently strong to define the concept of natural numbers, one can construct a statement that can be neither proved nor disproved within the system.” His second theorem states: “No consistent system can be used to prove its own consistency.”
17. Rosen, R.: *Anticipatory Systems*, Pergamon Press, New York (1985)
18. Nadin, M.: *Anticipation: The End Is Where We Start From*, Lars Müller Verlag, Basel (2003)
19. Rosen, R.: *Life Itself: A Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life*, Columbia University Press, New York (1991)
20. Berry, II, M.J., Brivanlou, I.H., Jordan, T.A., Meister, M.: *Anticipation of Moving Stimuli by the Retina*, In: *Nature*, vol. 398 (1999), pp 334–338
21. Ekman, P., Friesen, W.V.: *Facial Action Coding System: A Technique for the Measurement of Facial Movement*, Consulting Psychologists Press, Palo Alto (1978)

22. Fletcher, P.C., Anderson, J.M., Shanks, D.R., Honey, R., Carpenter, T.A., Donovan, T., Papdakis, N., Bullmore, E.T.: *Responses of Human Frontal Cortex to Surprising Events are Predicted by Formal Associative Learning Theory*, In: *Nature Neurosciences*, vol. 4, no. 10 (2001), pp 1043–1048
23. Ishida, F., Sawada, Y.F.: *Human Hand Moves Proactively to the External Stimulus: An Evolutional Strategy for Minimizing Transient Error*, In: *Physical Review Letters*, vol. 93, no. 16 (2004)
24. Nadin, M.: *Mind-Anticipation and Chaos*, Belser Verlag, Stuttgart (1991)
25. Minsky, M.: *The Virtual Duck and the Endangered Nightingale*, In: *Digital Media*, June 5 (1995), pp 68–74
26. Nicolis, M., Dragan Dimitrov, A.L., Carmena, J.M., Christ, R., Lehew, G., Kralik, J.D., Wise, S.P.: *Chronic, Multisite, Multielectrode Recordings in Macaque Monkeys*, In: *Proceedings of the National Academy of Sciences of the United States of America (PNAS Online)*, Sept. 5 (2003)
27. Quotone, E., Huckabee, K.L.: *Anatomy of an Effective Warning: Event Anticipation, Data Integration, Feature Recognition*, Preprints, 14th Conf. On Weather Analysis and Forecasting, Amer. Meteor. Soc., Dallas, TX (1995), pp 420–425
28. Guiasu, S.: *Comment on a Paper on Possibilistic Entropies*, In: *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, vol. 10, no. 6 (2002), pp 655–657
29. Feynman, R.: *Potentialities and Limitations of Computing Machines*, Lecture series, California Institute of Technology, CA (1983–1986)
30. Feigenbaum, M.: *Universal Behavior in Non-linear Systems*, In: *Los Alamos Science*, vol. 1 (1980), pp 4–27
31. BES, *The Scientific Rationale of the British Ecological Society (BES) Symposium*, March–April (2005)
32. Montgomery, R.: *Nonholonomic Control and Gauge Theory*, In: Canny, J., Li, Z., eds., *Nonholonomic Motion Planning*, Kluwer Academic, Dordrecht (1993), pp 343–378
33. Heisenberg, W.: *Uncertainty Principle*, first published in *Zeitschrift für Physik*, vol. 43 (1927), pp 172–198
34. Elsasser, W.M.: *Reflections on a Theory of Organisms*, Johns Hopkins University Press, Baltimore, MD (1998). Originally published as *Reflections on a Theory of Organisms. Hoilism in Biology*, Orbis, Frelighsburg, Quebec (1987)
35. Windelband, W.: *Geschichte und Naturwissenschaft* (1894) (cf. Strassburger Rektoratsrede. http://www.fh-augsburg.de/~harsch/germanica/Chronologie/19Jh/Windelband/win_rede.html)
36. Rosen, R.: *Essays on Life Itself. Complexity in Ecological Systems*, Columbia University Press, New York (2000), pp 324–324
37. Kohonen, T.: *Self-Organized Formation of Topologically Correct Feature Maps*, In: *Biological Cybernetics*, vol. 43 (1982), pp 43–69
38. Kohonen, T.: *Self-Organizing Maps*, Springer, Berlin Heidelberg New York (1997)