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SYSTEMS MOVEMENT

Autobiographical retrospectives

Systems movement: autobiographical retrospectives is a special section of this Journal, the purpose of which is to produce, via invited autobiographical articles, historical information and insights regarding the thought processes and individual motivations of leading figures in the systems movement. This valuable information is normally not included in regular publications, which tend to focus on results rather than the creative process leading to those results. The autobiographical articles are likely to help us improve our understanding of how, and why, the systems movement has progressed since its emergence in the mid-twentieth century. Each article in this section is published strictly by invitation extended to individual authors by the Editor, and is based on the recognition that these individuals have made major contributions to the systems movement.

MIHAI NADIN. Credit: Photo by Djahangir Zakhidov, ATEC/UTD

Reporting on anticipatory systems: a subject surviving opportunism and intolerance

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George Klir – in memoriam

Context

Almost 7 years ago, George Klir invited me to put my activity in some retrospective. I learned from him that in 1992 a reluctant Robert Rosen reminisced on his formative years. His acquiescence to the "duty to report" resulted in a document that is humbling to all of us. Rosen's impressive oeuvre did not emerge in a vacuum. The way we live and what we do are intertwined. Academia is a tough environment: Bertalanffy's heart attack ("killed by the system", as we learn from Rosen) and the demolition of the Center for Theoretical Biology in Buffalo (1967) testify to a narrative usually sanitized. In reality, science does not graciously advance to better understandings of its subjects or to acknowledging those very few who made such understandings possible. George Klir was also one of them.

Beginnings

My report harks back to a Romania of a time that does not want to be forgotten. When the moment came to decide, I was probably less clear about *where* I wanted to study (not much choice) than *what* I wanted to study. In February 2016, as my book *The Civilization of Illiteracy* was released in a Romanian translation (20 years after its original publication), I was again with the man from whom, in 1955, I asked for advice. Solomon Marcus, the eminent mathematician, founder of mathematical poetics, as well as mathematical linguistics, was then at the beginning of what became an illustrious career of encyclopedic propensity. What went through his mind when a high school graduate from the provinces (for those living in Bucharest, Braşov, my hometown, as well as every other place beyond the capital city, was "provincie", or countryside) asked him where he should go to study the subject of *creativity*, he never told me. "It was a crazy idea, like so many of Nadin's original views", were his words in describing the beginning of my activity to the packed auditorium of the School of Mathematics and Information Science at the University of Bucharest. (Two weeks after his presentation of my book, he passed away. At the age of 91, he was tirelessly designing a forward-looking course of education for Romania's youth.)

Somehow I ended up applying at the Polytechnic (Institutul Politehnic), competing for one of the very few spots available in the first class allowed to study what would eventually become computer science. Only one year before, the communist party declared cybernetics to be "representative of Anglo-American Imperialism".

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Figure 1. 1959: Research with Professor Alexandru Spătaru (left) and 2 of my colleagues: Marius Guran (right, leaning), who was later in charge of the RENAC/RENOD (Romanian network connected to the Internet), and Gheorghe Samachişe (2nd from left), prolific inventor who, at SanDisk in San Jose, brought his contribution to flash card technology.

The Polytechnic was the place where distinguished scientists found their academic home, sometimes in a kind of exile. Nicolae Ciorănescu, a Sorbonne-educated mathematician, was allowed to teach here after having spent time in jail – for political reasons. It was not unusual for other professors to come to his classes. Ciorănescu was witty but extremely exigent. Ion Agârbiceanu, also politically tainted, taught physics. My first research project took place in his lab (and concerned lasers; our professor was an expert in spectroscopy). Among our superb professors were Radu Voinea (who eventually became president of the Romanian Academy), Tudor Tănăsescu (expert in electronic circuits), Edmond Nicolau (cybernetics, and almost everything else), Gheorghe Cartianu, Alexandru Spătaru, and Mihai Drăgănescu (also a future Academy president) (Figure 1).

From Lyapunov to control theory and Aristotle's prolepsis

I was riding the tram on my way from the Polytechnic to the student dormitories when Marcian Guttman asked me, with his typical heavy stuttering, to solve a Lyapunov equation scribbled on his ticket (one inch long, less than half-inch wide). As Ciorănescu's assistant, Guttman was notorious for stalking students with math problems. You could not avoid or evade his questions. One theorem led to another, and so on, from differential equations to matrix calculus. After quite a few such sessions with a "travelling tutor" I did not ask for, at exam time I knew more mathematics than my friends studying it at the University of Bucharest – considered the better place for those wishing to become "pure" mathematicians.

The Polytechnic gave me the structured basic scientific and technological education in the absence of which my research would probably have evolved in a different manner. My thesis was on Control Theory. (It seemed, at that time, that being exposed to Lyapunov's

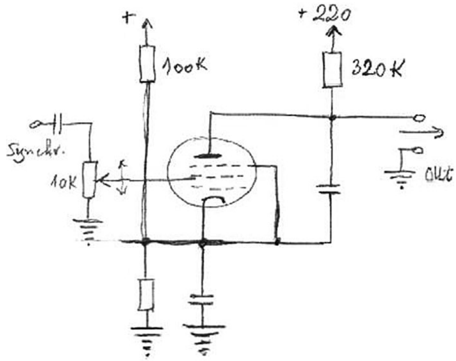

Figure 2. Saw-tooth generator (1960).

equation on my tram ride with Marcian Guttman was fortuitous.) Control Theory opened to me what would eventually become the subject of my entire activity: anticipation. In this respect, consider this less than innocent statement from Aristotle:

> If every instrument could accomplish its own work, obeying or anticipating the will of others, like the statues of Daedalus, or the tripods of Hephaestus, which, says the poet, "of their own accord entered the assembly of the Gods;" if, in like manner, the shuttle would weave and the plectrum touch the lyre without a hand to guide them, chief workmen would not want servants, nor masters slaves.

(The poet Aristotle made reference to was none other than Homer.) Anticipating the will of others, the shuttle would weave and the plectrum would touch the lyre without a hand to guide them – these were thoughts that could get a future engineer quite excited. But before pursuing such a challenge, I had to design and build a system, and I needed to describe it:

$$\text{State of system} = \text{function (control parameter)} \tag{1}$$

and express it mathematically:

$$x = f(c) \tag{2}$$

Actually my notes contain an interesting third expression:

$$x(t+1) = f(x(t)) \tag{3}$$

The domain of $x(t + 1)$, i.e. the future, contingent or well defined, was to progressively become my focus. I look back and smile. A linear control system, or even nonlinear controllers, seems now so simple. But at the time of the degree project it was not. The vector X space to which x belongs can be easily defined: let's say, the control system applies to controlling the speed of a bike. Things are less clear when it comes to control parameters: biking uphill, biking downhill, biking over obstacles, etc. They belong to a set of admissible parameters. The feedback mechanism (to "control" the control process) was less straightforward. System stability considerations made implementation even more challenging. To compensate for amplitude error caused by the delay time, I would use a saw-tooth generator.

Memories are always tainted by experiences accumulated over time. What the student of those days was thinking and what the graduate learned afterwards are different things. The student had to design, among other things, a function generator for the control process. A saw-tooth wave generator for the linear control was an engineering task. Here is the original sketch of the circuit conceived and built, using – Alas! for those reading my text in the age of integrated circuits – a vacuum tube, a pentode, of course (Figure 2).

What this sketch does not reveal is that "anticipating the will of others" suggests processes that remind us that what is alive develops over time, reproduces, and eventually ceases to have life. For the future engineer, real-time control meant to deal with mapping from the vector space of the system's states (x) to admissible controls (c). This constrained reality. Nature, however, always leaves room for fluctuations. The serious mathematics taught at the Polytechnic allowed the student I was at that time to understand that analytical geometry, calculus, vector analysis, and trigonometry were indispensable for describing how machines work. Engineering depends upon physics and mathematics. It took me another 25 years before I started questioning their usefulness, in the form I studied them, for describing life. I knew that the hand guiding the plectrum was not as precise as mathematics for engineers was in describing machines. Actually, in the realm of life nothing is precise.

Defense of the thesis was not unproblematic. The machine worked. But I was also supposed to justify it within the official philosophy of communism, the so-called "dialectic materialism". In this respect my project was found deficient. Combined with this were ideological shortcomings, and "stains" on my biography – one had to be of "Romanian" descent, with no "bourgeois" forebears, no relatives abroad, etc. You get from this the explanation why I was not offered a position at the Polytechnic to the surprise of everyone in my class, and many of my professors (those who survived the purge after the events of 1968).

It was for the better. (The "What if …?" speculation is of no interest here.) The Polytechnic gave me the awareness that creativity was not really hidden in the saw-tooth generator, but rather in Aristotle's anticipation, prolepsis as his concept was. It took luck to get the approval from the Minister of Education (a distinguished mathematician, Mircea Maliţa, eventually turned politician and diplomat) to pursue a second degree while I was working as an engineer. (The details are pretty interesting, but not for what I am trying to report on.) During this time, my contact with Solomon Marcus (in the meanwhile associate professor at the University) became more frequent. I went to some of his classes, and through him I met Grigore Moisil, the mercurial iconoclastic figure of Romanian mathematics. The experience in Control Systems, a domain of knowledge transcending engineering, gave me opportunities to argue in favor of a distinction that not even today is unanimously accepted. The machine can be fully controlled. The living, even in its simplest forms, changes continuously. It controls itself. In its dynamics, which means goal-driven behavior, it acquires its unique identity, its functionality. The dynamics of the machine is the expression of its design: it is supposed to accomplish desired goals. In contrast, the dynamics of the living is the result of interactions. Machines do not change. Their physical embodiment is subject to wear and tear. The living is identified through change, from inception to death. The machine and the living are different in their dynamics. The subject of change entered my life for good.

Aesthetic creativity

Pursuing the second degree meant bringing scientific and technological questions into a new gnoseological territory, not simply adopting the traditional questions of speculative aesthetics. The systems view of aesthetic activity was unheard of before that. Moreover, in the years after the Polytechnic experience and during the time of pursuing a second degree

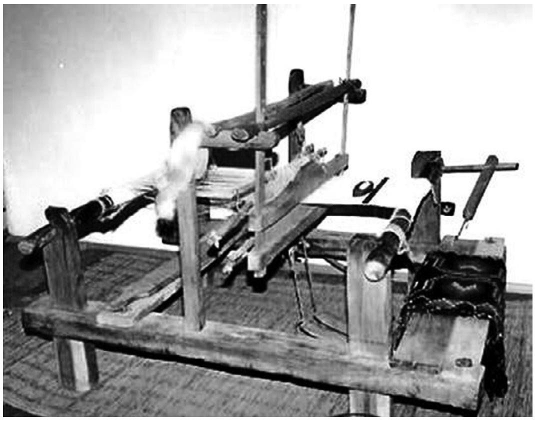

Figure 3. The "computer" before the computer.

in aesthetics, computation picked up and gained in acceptance. Therefore, it became even possible to formulate questions in computational terms.

If we are seeking knowledge, we'd better look for it in everything human beings do: science and art, thinking and feeling, reflected and unreflected activities, learned and autonomic forms of expression. At the Polytechnic, aesthetic considerations played a secondary role (mainly in the design component of engineering). In the aesthetics context, Aristotle's understanding of what it would take to have a world where our hands would do less (or nothing) was not an issue. Of even less significance was the computer, although in some form or another artists, in particular composers, never shied away from "calculating" and "performing" some of their compositions.

My understanding of computation was based on what I had studied at the Institute. Romania, with a respectable scientific tradition, was indeed ahead of other communist countries in building its first computer (the CIFA 1, 1955, mentioned in *Mathematical Review*, June 1958), under the direction of Victor Toma (a Polytechnic alumnus) and Armand Segal, at the Institute for Nuclear Physics. But their computer was not accessible to anyone outside the Institute. My intention was to describe the particular knowledge (defined later as aesthetic knowledge) that undergirds the acts of drawing, of painting, of turning sounds into melodies, of telling stories. Could images made from instructions given to a machine – regardless which machine – eventually be accepted as paintings, sculptures, music? Was it all knowledge, or was something else at work as well?

My initial, rather simplistic, understanding of what a computer is came about years before I'd even heard about the "dangerous machines" that would turn us all into slaves of capitalism (the propaganda of those years). I was still in high school when I first saw a weaving machine, a peasant's rudimentary loom. A peasant woman's hand was at work. Her good taste was not informed by any concept of art; she was not schooled in design (probably illiterate, as many poor people were in Romania before and after World War II). Her skills were picked up from her mother, or somebody in the family. No books read and no museum visits. She was creating with the same naturalness as in giving birth – itself a form of creation (Figure 3).

The artisanal artifact (no redundancy here: *artisanal* means made in a traditional or non-mechanized way, while *artifact* highlights workmanship of cultural or historic interest)

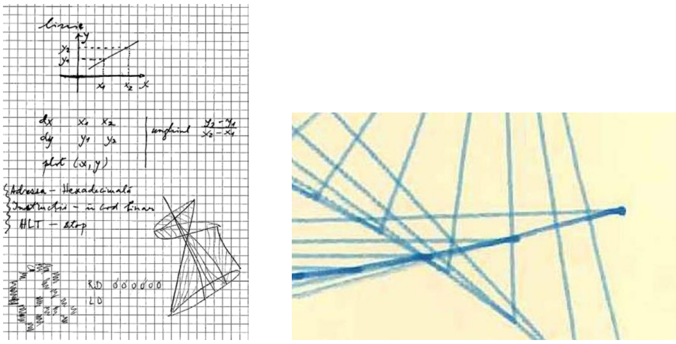

Figure 4. My "algorithm" for line drawing; discrete points making up a line on paper ("dripping effect").

allowed the weaver to select, combine, and integrate rows and columns of colored threads. Did Aristotle really mean that this creation could be performed without a hand guiding the process? It was at that time that one of my questions started crystalizing: Can we make machines that are creative? That is, machines that translate aesthetic anticipations into works of art? To be creative is to give birth to something that never existed before. With this premise came a bit of metaphorical description. Every birth is the outcome of inspired love, insemination, many struggles, pain – all in anticipation of, not in reaction to, the world in which the creation will find its place. Weaving can be art – reflecting the weaver's talent – or manufacture, a machine-based productive ability, different from that of aesthetic creation. Joseph Marie Jacquard's punched cards, Herman Holerith's mechanized census tabulation, and Howard Aiken's calculating device have a lot in common with the loom. Charles Babbage's *Differential Engine* even more (Lady Lovelace Objection not withstanding). However, they are implementations of algorithmic computing, as James Essinger has shown (*Jacquard's Web: How a hand-loom led to the birth of the information age*. Oxford University Press, New York 2004). As automated machines, they negate the interactive nature of creative processing on the loom.

Back to my involvement with computers and the question of anticipation. Finally, I had a chance to see the computer: stacks of cards, a rudimentary monitor, dials, thousands of vacuum tubes (cooled by fans). I had imagined it to be no less exciting than a loom. It was not. The outcome of computation was also disappointing. On those rare occasions when my ability to adapt to the stringencies of machine language programming (and to the hexadecimal system) made sense, all I got were strings of numbers, something requiring further deciphering.

Time reference: May–August 1966. What does it take to draw a line point by point ("raster" was not yet in my vocabulary) (Figure 4).

An improvised printer made it possible to see what I thought should be the outcome. In an article in *Leonardo* ("Science and Beauty", 1991), I gave some examples of my early work. Recently (July 2016), this work was again featured in *Leonardo* in the *Pioneers and Pathbreakers* series, documenting the beginnings of computer art. The crummy paper on which the drawings were plotted, by now yellowed and probably soon to disintegrate, testifies to a time when nobody thought of acid-free paper, not to mention archival quality printing. The lines are bluish, the "printer" often dripped. I concocted a cheap fountain pen ink, with a lot of sediment that blocked the syringe needle – a kind of a pen. The thickness of the lines varied, but not because I was able to make them of various weights (I wish I could have).

What you cannot see in these images is my confusion: Is this all? Drawing by hand was faster and more accurate. The loom was so much more exciting: it produced the canvas and the art integrated in it. Or was it the artist who operated it, the hand that Aristotle was so eager to eliminate? Indeed, Rembrandt's brush in my hands, or Picasso's various "tools", will not make me, or anyone else, the artist they were. And what about "anticipating the will of others", which seemingly Homer in his *Iliad* (to which Aristotle alluded) associated with the life of authentic art? Could a machine create Homer's poetry? (It can of course be imitated.)

The study of aesthetics was paralleled by my experimental attempts. Art, as I discovered, is made by artists. I was not one. The benefit of being exposed to creative processes gave me access to a more informed perception of art, which neither reading about art, nor visiting museums, nor listening to music in concerts can substitute. Although the experience did not turn me into an artist, it helped me understand that while algorithmic computers and looms are equivalent in many ways, they were also essentially different. The weaver did not need a control system – she had her own anticipation. In words I did not own at that time, this means that the desired outcome (a possible future) informed choices as they were made ("on the fly" in the jargon of programmers). You can play the violin by a method (let's say Suzuki), or by letting your own perception of the sounds you generate – what you want to hear – guide you. The gypsies of the time when I discovered the loom learned and played music by ear (not unlike the musicians of Appalachia, as I discovered way later, away from the place where I was born).

Weaving is an interactive anticipatory experience: it is open to randomness, to intuitive choices, to spontaneity. Algorithmic computation is an automated process unfolding according to a recipe: this is what it takes to draw a line. In hindsight, I understood that on the loom, the recipe ("algorithm" is what we call it today) and free choices fuse into the surprise and discovery characteristic of art – at least in my understanding of it. Art, as a particular expression of creativity, is not reducible to a formula. It is not algorithmic. Production (and re-production) is algorithmic. But at that time, I could not come up with such words, even less with such an understanding. Clarity is achieved by defining the language used in describing what we want to understand. There is no knowledge independent of language (which can be the language of mathematics, of chemistry, of music representation, of visualization, etc.).

In the Romania of that time, of many deprivations, to think freely was even more difficult than to get access to a computer (not to mention the necessities of life). It was a polarized world: the communist regimes demonized cybernetics and computation as instruments of diabolical capitalism conceived predominantly for military purposes. Yet, they used the new machines – when they got some – predominantly for spying on the population. The ends justify the means! It was in this context that one of Romania's brightest minds, Grigore Moisil, exercised his genius (charm being part of it). And *voilà*, an IBM 360 arrived at the University Computer Center (CCUB), located at Strada Mircea Vulcănescu 125. (Before that there was a British ICT machine used for the census and, as mentioned, the machines conceived at the Institute for Nuclear Physics.) After Romania built machines (1969, the *Felix* computers), access to computers became somewhat easier. It was a time of opportunity for those who realized the potential of automated mathematics.

UNIVERSITATEA BUCUREȘTI
Fac. de matematică și fizică
259
Anul 1971 luna februarie 11

Propuneri privind invățămîntul informaticii la
Facultatea de matematică a Universității
din București

Raport alcătuit de Gr.C.Moisil

Formarea informaticienilor în Facultatea de matematică a Universității București se face prin grija exclusivă a catedrei de Teoria algebrică a mecanismelor automate, și anume prin cursurile acestei catedre, despre evoluția cărora decanatul este informat din planurile de activitate ale diferiților ani, prin activitatea la Centrul de Calcul al Universității București și prin munca individuală.

Asupra perioadei anterioare plecării mele de la Centrul de Calcul am referit în raportul de activ... de Calcul al Universității București publ... 1970, pe care îl înaintăm alătur... cum a început formarea ...

In ... ...ații noastre. postu... ... filozofie, vă vom face

...ebuie să subliniem că, deși în vara anului ...ut o lucrare de diplomă asupra logicii deontice ...ilizării calculatoarelor în cercetări juridice, totuși nu s-au făcut progrese în acest domeniu.

11.2.71.

Gr. C. Moisil

Figure 5. (a) Moisil prepared a plan for teaching computers in Romania. (b) Moisil and the first group of students who got access to the new machine.

It made a difference that early on a distinguished mathematician recognized the opportunities associated with computers and worked out a plan (dated February 1971, Figure 5(a)) for a solid education in computer science. His text alone deserves to be discussed one day by those who realize that technology is far ahead of our understanding of education in the age of computation. (As far as I know, only Edsger W. Dijkstra approached the issue at a comparable depth level.) The students were enthusiastic at the prospect of learning about the new machine (Figure 5(b)). It meant so much for their future.

For me, computation was already beyond the focus on numbers and calculations faster than those a human being could perform. Could it play a role in enabling creative activities? Would artists want to continue the tradition of calculating some of their work? (Mozart created a game of dice, called *Musikalisches Würfelspiel*, whereby a pair of dice is rolled several times to create a minuet. It was fun to recreate his experiment!)

I wanted to make images and sounds for reasons different from those that motivate artists. Fully aware of my more than modest achievements – intersections of curves, attempts at describing concave and convex functions, ambitious formal descriptions of what is called the dynamics of the image – I showed my images to Moisil (Figure 6).

He gave me his lectures, *Lecţii despre logica rationamentului nuanţat* (Lectures on Nuanced Reasoning). It was also the time I was discovering Zadeh's fuzzy logic – Romanian mathematicians (Negoiţă and Ralescu, 1974) were among the first to associate themselves with it. In a society of clear-cut distinctions ("You are with us or against us", was the official slogan), fuzzy was a good place to introduce degrees of belongingness. Fuzzy was to play an important role in my attempt to deal with the imprecise characteristic of creative processes.

The dialog with Moisil was way more useful than the many weeks I spent trying to make those images. The making of art, in his view, involved, on an intuitive level, multi-valued logic – the domain where he felt "at home". It is an activity that transcends our ability to describe how a certain work of art came into being. Many possible choices inform an artist's aesthetic decisions that are pretty unique (the originality factor). Keep in mind: this was Romania in 1973 (shortly before Moisil died). Those were visionary thoughts. Many ideas

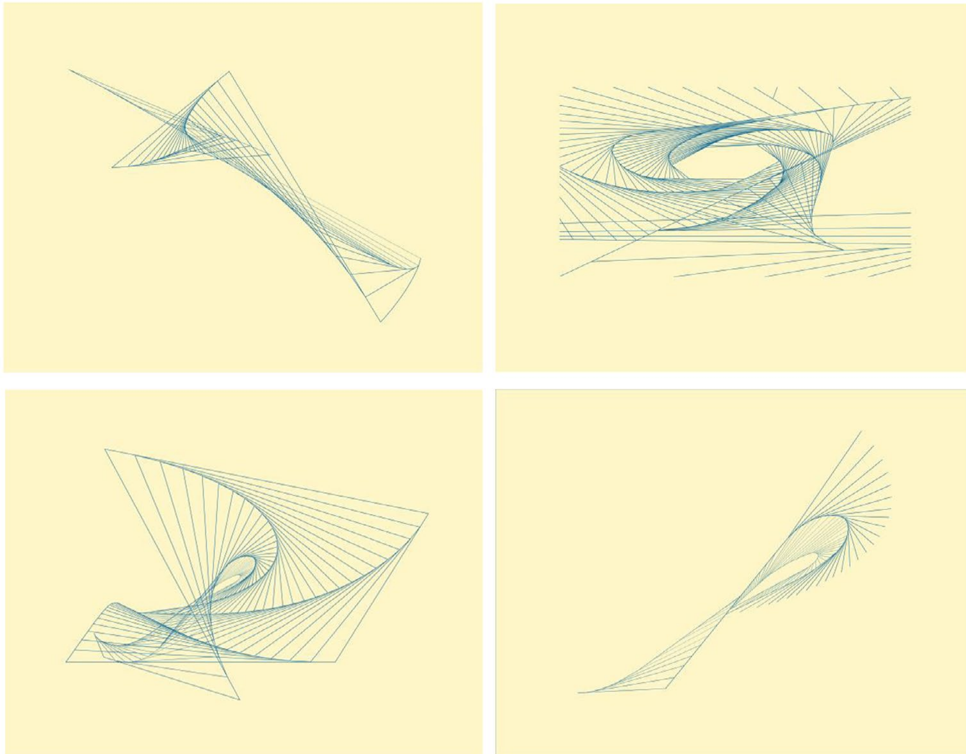

Figure 6. Early computer graphics: mathematics and aesthetics.

came up in various conversations with others (some of whom were blacklisted, as I myself would eventually be). Mathila Ghyka (ahead of Le Corbusier's *Measure of Man*) and Pius Servien came to my attention. Since they were living in the West, access to their writings was extremely limited. Their names could not be mentioned openly.

Looking back at my early images and considerations of the computer's role in generating aesthetic artifacts, I can identify the questions I was trying to address. Machines are efficient in producing sameness, not uniqueness. The living, however, was always expressed uniquely. Aristotle thought that no two blades of grass are the same. I would find out, eventually, how different living cells are. Moreover, I learned that there was a renewal of the matter from which the living is made. Not only does a scratch heal by itself, but all cells are renewed. The living is in a continuous state of self-creation. Its own renewal cycles are such that we are in a state of always being new (even at old age, although the rhythm of renewal is slowing down). The matter making up a stone, or water, or an acid remains pretty much the same. Would that mean that algorithmic computers, by their condition, are not conducive to creativity? Moreover: all beginnings (of children, ideas, theories, for example) are mimetic. Imitation is the first step toward one's own expression. Are machines bound to remain a medium of imitation? For example, Noll, the Bell Lab pioneer of computer graphics, thought he was making art when he produced images à la Mondrian. I was too far away from him to challenge his views. Deep learning based computations, fashionable in our days, imitate not only Mondrian – but this is a different matter. What kind of art can be generated with computers that could not be made otherwise? A new aesthetics became possible for those dedicated to creatively appropriating computational means within an integrative systems perspective of art.

To know starts in the act of representation

In addition to Moisil, I had the chance to spend time with Solomon Marcus. His genius in bridging between mathematics and semiotics most certainly influenced my intellectual path and continues to inspire me. Solomon Marcus encouraged me, and so many others, in every possible way. I was trying to read *The Collected Papers of Charles Sanders Peirce*, since semiotics – conceived by Baumgarten as part of aesthetics – came into the larger picture. Well, Professor Marcus xeroxed eight massive volumes for me. Today, nobody can understand what this meant in a society where access to libraries was a political issue, and even Xerox copies were indexed.

The meaning of representation became a subject because Peirce's semiotics made it clear to me that not everything is an expression of quantity, or can be understood only in terms of numbers. Art came up in relation to Max Bense's informational aesthetics: "Nur künstliche Kunst!" (Only artificial art) was his provocative formula. Randomness was supposed to substitute for the living artist. If this were the case, creativity and the underlying anticipation would be a random number generator. The myth continues to have currency even in our days, especially among those producing deterministic theories of how and why art is created. In touch with the Stuttgart School – famous for stimulating the first computer art show in Europe at the Galerie Niedlich, Stuttgart, November 1965 – I wanted my images to be acknowledged not for their artistry, but rather for the questions arising from making them. The curiosity of those who coalesced around the rather temperamental master that Bense was led to an invitation to join their group. They were very dedicated to Peirce's semiotics, better known in Europe than in the USA. Frieder Nake was one of them. The mathematician turned computer science professor and artist of the computation age – yes, he is an artist – remains a close friend to these days. Aesthetics, semiotics, and computer graphics, occasionally Marx, who inspired Nake's social and political activism, are subjects upon which we endlessly dwell.

The dogmatic, deterministic perspective of the Stuttgart School, where information aesthetics was first defined, worried me. David Birkhoff, whose name is usually associated with the ergodic theorem (as well as with anti-Semitism), introduced, in 1933, the Aesthetic Measure (title of his book) – which Bense liked since it quantified aesthetic descriptions. Information aesthetics was not compatible with what my research taught me: creativity is an expression of anticipatory processes unfolding only in open systems. Knowledge acquisition starts with descriptions of reality, quite often in terms close to fuzzy descriptions. (Bense could not stomach the notion of fuzzy sets.) The Humboldt grant awarded to me (1978) was associated with Bense and Stuttgart University. To be hosted by a prestigious academic institution, supportive of my accomplishments, was enticing. To work with an intolerant famous colleague was less attractive. Therefore, I was prepared to sacrifice the award out of principle. The grant was saved by the legendary Wolfgang Stegmüller, of the Institute for Philosophy, Logic and Theory of Science at the Ludwig Maximilian University of Munich. He did not question my fundamental position, but wanted it established on a firm logical foundation. Stegmüller was dedicated to scientific philosophy (in the spirit of the Vienna

Circle), and enjoyed the company of those who shared in the rationality of knowledge acquisition (embodied in his Institute's program) and of *Erkenntnis* (the journal he published with Hempel and Elser). It was not a compromise – second best to Bense – rather, a chance: at that time Stegmüller authored about incompleteness and undecidability (*Unvollständigkeit und Unentscheidbarkeit*, 1959), a subject already on my own agenda. (Reading Gödel was one of the first things I did after settling in Munich.)

Value theory

Basically, I escaped from Romania – the regime later sentenced me *in absentia* for never returning. My family (a USA-born wife who, heroically, settled in Bucharest in the grey years of Ceausescu's dictatorship, and our three very young children) remained in Bucharest, hostages to vouch for my return. Taking advantage of the political reality between the powerful USA and a Romania that wanted better trade relations, my wife succeeded in obtaining visas for our children (whom the Romanians considered their citizens). We reunited after I had started research in the elegant environment of a university conveniently located near the famous *Englisher Garten*. To express gratitude to all those who helped, in Romania and abroad, is significant for how I understand the connection between what we believe in, what we share with our students, and what we actually do in order to make our ideals part of reality. A comprehensive value theory, as I was trying to establish, could not escape this basic understanding of the relation between what is real and what is possible.

Zadeh's possibility theory (1978), sketched rather summarily in his first paper on the subject, was inspirational. Over time, the idea it expressed percolated in the description of anticipatory systems. But what helped most in expressing my own views was the new mathematics of Category Theory. It was significant for Rosen – who got it from the source (Eilenberg in New York and MacLane in Chicago) – and was of direct use in the value theory I proposed. I had no idea at that time who Rosen was, or what he was studying, never mind the mathematics he adopted. He wanted to work in the mathematics of biology; my focus was on the scientific foundation of a theory of creativity and the underlying anticipation. But independent of each other we adopted a particular form of mathematical description of the subject we were pursuing. What was decisive is that it dealt with structural properties rather than quantitative distinctions. For me, system is always associated with process, and at that time Category Theory was the closest language we had for describing process. More than 50 years later, I learned that in the Soviet Union a distinguished group of researchers (from physiology, psychology, brain science, linguistics, etc.) were trying to capture their early ideas regarding anticipation expression through some mathematical description. To this end, Gelfand, Latash, Tsetlin, Feldman, and others interacted with Bernstein, Anokhin, Ukhtomsky, Uznadze, Beritashvili, and their colleagues.

What distinguishes our respective choices is reflected in the fact that semiotics became the entry to the knowledge I was seeking. More precisely, representation. In order to know something, we represent it and actually work on representations. This applies to everything of gnoseological interest. The formalism of Category Theory allowed me to reconstruct semiotics in a language that reflects awareness of relations. "Nothing is a sign unless represented as a sign" means nothing other than the category *sign*, and the associated morphisms (sign operations) standing for the sign process (semiosis) leading to meaning. With this in mind, and enjoying the intellectual context of discussions with mathematicians and logicians, the work on value became my *Habilitierungsschrift* – the dissertation for the highest academic degree, which entitles the person to teach in a university (*facultas docendi)*. It was published (G. Narr Verlag, 1990), to a rather limited readership. Written in German, the book advanced ideas upon which my future contributions rest. In particular, distinguishing between the meaning and data domains. *Data are significant only to the extent they are associated with meaning.* This association takes place in the living, at all its levels: from cells to the whole organism, and to interactions between living entities and the world. It does not take place in non-living embodiments. Finally, the distinction between the decidable and the undecidable (which eventually became the criterion of complexity I am advancing these days) goes back to that time.

The MIND

What the Center for the Study of Democratic Institutions (Santa Barbara, under the direction of Robert Hutchins) became to Robert Rosen (many of his original contributions are associated with the Center), the *Institut für Philosophie, Logik und Wissenschaftstheorie* at Ludwig Maximilian University became for me. Distinguished colleagues, such as Godehard Link, Felix Mülhölzer, Wolfgang Spohn, et al., engaged me in lively discussions and challenged my views. Stegmüller wished that I follow him as the director of the Institute (at his retirement, 1990); but I had my own agenda. Those who would like to reconstruct it from my successive appointments would have a difficult time. I taught Design Theory and Semiotics at the University of Essen; taught Philosophy and Semiotics (respectively, in the Schools of Liberal Arts and Design) at the Rhode Island School of Design (the "Harvard of the Arts"), where I introduced computers in art and design education; taught (as adjunct faculty) at Brown University (participating in the *Electronic Book* project initiated by Andy van Dam – the preeminent computer graphics guru of America – and Steve Feiner, currently at Columbia University); interacted with the Media Lab at MIT (offering classes in the semiotics of the visual and in interface design); and was appointed Eminent Scholar in Art and Design Technology (a chair endowed by the State of Ohio) at The Ohio State University (Columbus). In Columbus, I elaborated a plan for an Advanced Computing Center in Art and Design (ACCAD). A counter-proposal was the Center for Advanced Computing in the Arts (CACA; the acronym explains why the group took over my title, but not the plan). Theirs was a mechanistic-driven program, producing more and more of the flying logos that fill our monitors (TV or computer graphics). They expected me to align with their understanding of creativity as a machine outcome.

In the Panel Session on *The Aesthetics of Computer Graphics* that I chaired at SIGGRAPH '85, the subject of creativity vs. automated machine production of images was passionately debated. Out of the entire panel only the late Hiroshi Kawano of Japan, himself distinguished in system theory, understood my argument. Indeed, I offended computer graphics industry leaders speaking about the dangers of "canned" art and suggesting that "If you saw one computer image you saw them all". Art by recipe is ontologically different from that of intention-driven creative processes.

Academia is famous for the reckless politics through which egos are expressed and less than honorable goals are pursued. In a day and age of obsession with funding at any price integrity is often the victim. Many have written about it – most famously, John Simon (in *New York Magazine)*: "The intensity of hatred, infighting, and back-stabbing increases with the marginality of a profession …". Rosen experienced it in ways that affected his activity and his health. Remember his testimony – "… brutal upwelling of resentments, jealousies, and low parochial politics" – in describing how the *Center for Theoretical Biology* at SUNY-Buffalo was abolished (in 1967).

The experience in the "golden cage" of the endowed chair at ACCAD caused an initial shock. Under communism, university administrators forced faculty members to execute party plans. In a free society, one expected, idealistically, that the best ideas would succeed. It did not happen. Tenure protects the employment of a faculty member, but not the freedom of creation. The Dean (who misrepresented the expectations associated with my endowed chair), together with a master of tackling football player (at the level of All American Hall of Fame) seeking glory in the illusion of commercial art, undermined my research because I would not align it to their agenda. In short, since my views, which I was not willing to compromise, conflicted with those of who were in control, I ended up isolated. Shunned by those who attracted me to OSU, I resigned (a tenured endowed chair!). It was a blessing that the system did not suck me in. Building upon research done in Munich and continued in Columbus, my lecture at the Graduate School introduced a new theory: *Mind – Anticipation and Chaos*. It is a dynamic systems mind theory that submits the hypothesis that mind processes are anticipatory in nature. The lecture was the basis for a (flattering) publication under the same title, in the Belser Presse series *Milestones in Thought and Discovery* (1991). (In this series, Belser published, for example, facsimile editions of Leibniz's text on his digital system of notation, texts by Carl Friedrich von Weizsäcker, William Harvey, Werner Heisenberg.) With this book started my short interaction with Robert Rosen, who wanted to read the book, as I wanted to read his. It is almost impossible to express gratitude to those colleagues who give us the gift of their consideration, even during tough times. Without interaction we can get choked in our own insecurity and doubts. At 1501 Neil Avenue in Columbus, at the Cranston Center, I felt like those who were forced to wear their Yellow Star in the ghettoes of Europe.

A second Cartesian revolution

Anticipation is definitory of the living. Acknowledging anticipatory processes, which empirical evidence suggests underlie evolution, is the premise for seeking knowledge of how change affects the living. It necessarily leads to the understanding that the Cartesian view of the world, i.e. the reductionist–deterministic description of physical processes, has to be complemented, in Niels Bohr's sense of complementarity, with a holistic non-deterministic view of life.

In respect to these hypotheses, which result from a rather intense teaching and research activity, a short biographic detour becomes necessary. For mainstream research, there are quite a number of paths that can be pursued. This is an age of a very rapidly expanding base for academic activity. Society can afford the luxury of stimulating research, even in view of relatively low return on the investment. In our days, as in the past, of research at the mercy of those who finance it, opportunism dictates the scientific agenda. And obsession with high returns (profit) eliminates (or undermines) everything else. To align oneself with the dominant direction is understandable. To challenge dominant views is the exception. Rosen challenged biologists and ended up in a decently funded position in Nova Scotia – far from where an intellectual of his talent and originality should have been. But that did not prevent him from pursuing his agenda and from publishing. Without suggesting any comparison to Rosen, or to anyone else who experienced the same (such as Walter Elsasser), I take note that swimming against the current can be difficult at times. C. S. Peirce, about whom Bertrand Russell wrote that he was "certainly the greatest American thinker ever" (cf. *Wisdom of the West*. Paul Foulkes, ed. London: Crescent, 1977. p. 276) had a similar destiny.

My chair in Computational Design at the University of Wuppertal gave me what German University professors still have: a certain autonomy. Computational Design, a discipline I founded (1994), advanced the notion that design is anticipatory, and that computation, in embodiments different from the algorithmic (non-Turing machines, AI, embedded hybrid analog and digital processing) can serve in the design process. It was by no accident that at the *Emeritierung* ceremony – one is retired at age 65 – I presented my book *Anticipation: The End is Where We Start From* (basing the title on a line from T. S. Elliot's *Little Gidding*), superbly put in page by Uwe Loesch. I also reported on the antÉ Institute for Research in Anticipatory Systems (initially incorporated as non-profit in Germany). The Institute came with me, more a shell than anything else (all the funding stayed behind in Germany), but was eventually welcomed at the University of Texas at Dallas (UTD) – where it is still hosted. Ambitious projects (*Seneludens*, Classifying Human Motion, Anticipation and Risk Assessment, Hybrid Control Systems, Virtual Architecture, Anticipatory Computing, etc.) were begun. The Institute, the first known entity fully dedicated to the study of anticipation, enjoys a growing membership. Indeed, the Institute is dedicated to establishing a shared knowledge foundation and to promoting cooperative efforts. At UTD, I designed and implemented the first experimental environment for quantifying anticipation – the AnticipationScope™ – or at least for acquiring data documenting anticipatory processes, in particular anticipatory expression and its physiological correlates. (This work was reported in an IJGS article, "The anticipatory profile. An attempt to describe anticipation as process", 2012.) In 2013, I discovered Nikolai A. Bernstein's *cyclography* and *kymocyclography* (from the late 1920s). His focus was on the correlation between the motoric expression and physiological activity, which, in different contexts, we both pursued.

Most important in the activity of the antÉ Institute is the collaboration with Hanse Institute for Advanced Studies (Hanse Wissenschaftskolleg, Delmenhorst, Germany). At the Institute I enjoyed a one-year sabbatical that resulted in various publications and presentations. Since 2012, the Hanse Institute hosts a Study Group in Anticipation, which has so far organized three major international conferences: *Anticipation: Learning from the Past. The Russian/Soviet Contributions to the Science of Anticipation; Anticipation Across Disciplines; Anticipation and Medicine*. These were major efforts, and resulted in three volumes (in Springer Publishers *Cognitive Systems Monographs*) and an IJGS special issue, *Russian experimental and empirical contributions informed by an anticipatory perspective* (with Andres Kurismaa as co-editor).

Understanding anticipation

Over time, anticipation expression of all kinds – i.e. successful actions that preserve life and help reach desired outcomes – has afforded a rich body of empirical evidence. However, experimental evidence, in the strict sense of the practice of creating closed systems within which causality can be tested, is practically non-existent. I would go as far as to claim that the vast majority of experiments involving the living (medical, psychological, sociological, etc.) are suggestive of the extent to which scientists will go to force physics-based descriptions on reality. When 80% of such experiments cannot be replicated, the message is clear: the hypothesis under whose guidance they are performed is wrong. Nevertheless, reducing the living to physics has become the priority in government-supported funding, and informs editorial policies of leading journals – exactly those publishing results of misguided so-called experiments.

In recent years, data pertinent to anticipatory processes have been systematically accumulated in a variety of fields of knowledge. This evidence triggered a plethora of explanatory attempts – some anchored in science of unquestionable integrity, the majority, however, rather speculative. The latter are usually derived from ill-defined concepts, or, worse, through less than grounded generalizations. In particular, the notion of "anticipation" itself is usually confused with other descriptions of change, such as forecasting, expectation, and guessing, and especially prediction. Conceptual clarity, more than instrumental obsession – let's measure it, we have the technology for it – so typical of this particular time, is necessary. Everything is measured – because it can be – in the hope that "big-data" technology will reveal "secrets" behind the data. The assumption is that all processes, regardless of their nature, are reducible to data based upon which prediction, forecasting, guessing, etc. are performed. Two aspects have been ignored: 1. data processing carries with it assumptions that ultimately falsify the data; 2. actions informed by anticipation, i.e. as an expression of life, are the outcome of *significant* data – usually "little" data, generated ahead of the action. Moreover, the emphasis in anticipatory processes is on *meanin*g rather than on quantitative descriptions based on the use of numbers.

If the above lines of this report read as a synopsis, it is because it left out the many interactions with colleagues interested in the subject. At Stanford University, Terry Winograd, whose disappointment with the mechanistic view of AI, placed him at the periphery of the computer hype. We discussed what he defines as lack of progress in computation regarding creativity, insight, and judgment. The combination between my anticipatory perspective and semiotic considerations helped build a relation reflected in the study I wrote during my short tenure at the Center for the Study of Language and Information (Anticipation – A Spooky Computation, 1999). During the same time, Paul Pangaro (so close to Gordon Pask's goal-directed systems) facilitated productive encounters with Heinz von Foerster at his Pescadero residence. "Die Ursache liegt in der Zukunft" (The cause lies in the future), a formulation bearing von Foerster's signature, became a suggestive definition of anticipation from the perspective of purposefulness. Like Winograd, who eventually ended up advising the founders of Google, Lotfi Zadeh proved to be an inspirational host during my activity at UC-Berkeley. In his *Foreword* to my book mentioned above, Zadeh suggests that a perception-based form of computation could eventually help in expressing anticipation. I still hope that some of his students will follow up on this idea. The dialog with Zadeh continues to this date – so much to learn from him.

Discoveries

UC-Berkeley also meant my discovery of Walter Elsasser. Harry Rubin, Professor Emeritus of Molecular Biology, wrote the introduction to Elsasser's *Reflections on a Theory of Organisms. Holism in Biology.* This is a very relevant attempt, by a reputable physicist (who worked with Schrödinger, among others), to establish a foundation of biology that reflected its specific condition. One quote from Rubin's text: "Elsasser argues … that the structural complexity of even a single living cell is 'transcomputational' – that is, beyond the power of any imaginable system to compute". Beginning from this insight, Elsasser leads the reader through a step-by-step process that ultimately arrives at the conclusion that living and non-living matter are separated by "a no-man's land of irrationality".

That Elsasser and Rosen, each on his own path to define the living, arrived at the same conclusion regarding computation deserves a short digression (for the sake of principle). My own views are informed by an understanding of computation that benefits from the realization that there are forms of data processing, such as interactive computation, that make anticipatory expression possible (*Anticipatory and Predictive Computation, Encyclopaedia of Computer Science and Technology,* 2016). Neither Elsasser nor Rosen, even less myself, would claim that he was the first to question the validity of the Second Law of Thermodynamics in the realm of the living. Claiming credit for one idea or another, or being given credit, is quite different from practicing science as a sports competition (Who came first?). Ideas are part of the larger architecture; they are related to other ideas. This is what justifies them. There is evidence that Elsasser was denied a Nobel Prize because of what critics identified as his *vitalism* – and this despite his arguments against vitalists. In the 1930s, Beritashvili, another Soviet precursor of a science of anticipation, defined the spatial navigation system for which a Nobel Prize in physiology was awarded many years later, in 2014, to others. His contribution was not even brought up in relation to the historic record. Rosen, in whose name a prize was awarded at a self-styled conference misusing his concept (after he was un-invited to it, during his last year of life!), never received the recognition his work deserved. Ironically, his mentor, Nicholas Rashevsky, founder of mathematical biology, had the same experience. He came up, just to give an example, with the first model of neural networks, but credit is given to one of his students.

Given Rubin's work in cancer research, we had many conversations on the subject. The most prominent medical innovations are the attempts at surgical removal of the cancerous growth, medication to halt proliferation, establishing a "firewall" (where laser treatment comes into the picture) for containment. All these methods are based on the deterministic model of cause-and-effect associated with grueling chemotherapy (itself a major innovation that, despite its side effects, has helped save many lives). Albeit, no cure for cancer has been discovered or invented. Rubin realized that the question to be asked is not "How do we get rid of something as organic as life itself, without getting rid of life at the same time?" His data, collected over decades, show that as long as healthy cells surrounding cancerous cells keep the latter in check, no cancer develops. My own hypothesis, articulated in those days, is that stimulating anticipatory capabilities, characteristic of the living, is probably the answer. Instead of dwelling on the innovation that pills and surgery represent, let us examine the information exchanged by cells, and identify under which circumstances healthy cells no longer recognize in advance the dangers associated with the unchecked proliferation of cancerous cells.

Mediocrity is corrosive

One suggestion for anyone seeking interaction: stay away from mediocrity. It is corrosive. Those who have earned respect and recognition are usually eager to broaden their horizon. I am not willing to name (or even further allude to) the mediocrities that made work more difficult, in ways that recall the destinies of Bernstein in the Soviet Union and of some of my professors in Romania. Bertalanffy's experience, Elsasser's marginalization, and Rosen's difficult academic path are examples not to be forgotten. When science becomes a matter of opportunism, of ideology, of unprincipled competition for funding, of vanity, of entertainment even, we all lose. An abusive provost screaming at faculty members or a lying dean (recruiting talent with false promises) is part of a pathology shared by totalitarian communism and corrupt capitalism. Rosen wrote explicitly about such phenomena because, as an intellectual of integrity, he could not ignore their poisonous influence. The painful memories of scientists forced to recant theories not aligned with dogma are from a reality that affected destinies and the development of science.

My invitation to Zadeh to speak at UTD occasioned his advice: "Energy wasted in challenging authority has no return in our work". Of course, he discovered what it means to stick to ideas not aligned with the most recent fad. In many instances, we talked about the need to overcome the extreme segmentation that marks our time. During Vint Cerf's visit to the antÉ Lab, I wanted to hear from the then ACM President why Lotfi Zadeh was never awarded the Turing Prize. For the record: Vint Cerf belongs to those who did not need my prompting. He was, by the way, swift in asking for the reasons that led to my decision to resign from the ACM. As an organization of professionals in computation, ACM never questioned the role computation plays in making possible the never-ending wars the USA started, the mediocrity of computer products (which Dijkstra long ago deplored), the surveillance of everyone, the submission of computer science education to corporate expectations. Let us be clear: social aspects of anticipation are not a marginal subject. Rosen took note in his report that "social structures realize relational patterns which individual organisms do". When this ceases to be the case, the open system is actually closed, its dynamics changed – a phenomenon we notice in the USA of our days. The sustainability of the American way of life, envied by everyone else who makes it possible, is a matter of anticipation.

A question of scientific legitimacy

What often undermines the attempt to suggest a new perspective is the reductionist tendency: open system, it has been argued, is actually a closed system "canonically perturbed" (Rosen's words); non-determinism is actually determinism. Non-deterministic Turing machines (NTM) are, according to this view, equivalent to deterministic Turing machines (DTM). This goes as far as to claim that DTMs can simulate NTMs. The same kind of thinking suggests that non-algorithmic computation can be simulated on Turing machines (algorithmic by definition). Most egregious, but with the longest tradition, is the belief that a holistic view is preserved within the reductionist methodology, despite the evidence that each reduction means a loss of information. Even the unfortunate idea that data is information belongs to the same. Anticipation defines the living as a dynamic interactive open system. Anticipatory processes, holistically engaging the system, are expressed in action. They are non-deterministic. The living does not know repetition – unlike machines. Some anticipation action succeeds, some does not. Between the creative effort and the pathology of delusion, the distance is smaller than we would like to acknowledge. Superstition is not so far from insight and inspiration as generally assumed.

It was not an apple falling from a tree (and the equation describing it) that gave legitimacy to the law of gravity. Newton advanced an understanding of physical law that revolutionized science, and continues to have practical relevance. The same can be said in respect to the theory of relativity: Einstein became more famous for $e = mc^2$ than for the revolutionary view of the universe that his mathematics advanced. It might be that quantum mechanics, still at the forefront of science today, qualifies as well as a revolution in thought and discovery. The fact that particular aspects of quantum mechanics (such as entanglement and non-locality) fascinate the public (and even some scientists) should not affect awareness of a totally new view of reality.

Human dedication to understanding the world, within which the living unfolds, eventually crystalizes in revolutionary views. This in itself is worth celebrating, but it invites reflection as well. Nothing comparable, not even the famous DNA helix, is on record in explaining life itself. Newton, Einstein, the quantum mechanics visionaries (Heisenberg, Schrödinger, Bohr, Feynman, among others) are present – and rightly so – in the explanation (as tentative as it still is) of the beginnings of the universe. But the beginning of life is still in the fog of confusion. The attempts to start life from non-life, almost as seductive as alchemy (which Newton upheld), take new forms (Venter's claim is only one among many). They entail a rather disconcerting surrender, celebrated as victory: since the living is embodied in matter, the more physics we know – and the more physics-based biology we use – the better we will understand life. The obsession of particle physics (i.e. know the particles and you will know all about the whole they are part of) translated into the hope that molecular biology or genetics will eventually solve all the mysteries of disease and, eventually, of life. Supervenience is an expression of the same.

Obviously, there is much more nuance to all of this. So far, science consists mainly of convincing physics theories and their extension into particular phenomena (chemistry, for instance). The material substratum is acknowledged without reservation; omitted is the understanding that the dynamics of the physical and of the living are different. Also absent is the distinct effort to advance a view of the living that defines its own characteristic causality. This might integrate the science of the physical – e.g. physics, chemistry, geology, meteorology – without discarding what defines a science of the living proper. The epistemological effort that I argue for might even arrive at the realization that physical causality (explaining change in the non-living) is a subset of the extremely rich types of causality that explains change in life.

For accomplishing such a daunting task, the focus should be on dynamics: *how* and *why* change takes place. Empirical evidence suggests that change in the non-living realm takes place at a timescale different from the many timescales characteristic of living processes. Moreover, in the physical, the timescale is relatively constant. In the living it varies under the influence of context – sometimes defined as *Umwelt* (cf. Uexküll), i.e. the perceptual world of a specific being: "Organisms are subjects interpreting their life worlds, not mechanical objects reacting to external forces". There is no birth and no death (short of misappropriated metaphors applied to stars and black holes) in the physical. And there is, contrary to poetic license, no intentionality either to be observed or experimentally documented.

The above is not mentioned merely for the sake of theory. It would benefit the community of researchers to have Rosen's contributions at the *Center for the Study of Democratic Institutions* (1976–1977) made available in a critical edition. The subjects addressed remain of undiminished actuality. Let me mention here "Some Temporal Aspects of Political Change"; "On the Design of Stable and Reliable Institutions"; "Environmental Challenges and Political Challenges"; comments on Watergate, etc. In one of these texts, the following aphorism comes up: "… it is much more dangerous to be misinformed than to be ignorant" ("Some Comments on Global Science Policies", 1973). At times, the writing reads like a

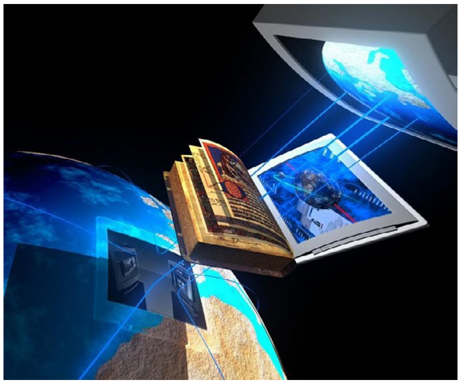

Figure 7. Cover of *The Civilization of Illiteracy* (computer image realized with the cooperation of Thomas Overberg and Stefan Lehmann).

commentary on current life in America (and in the world). The relational patterns in the living that Rosen noticed and generalized to political, economic, and cultural aspects are, of course, different from those I addressed in *The Civilization of Illiteracy* (1997, Dresden University Press).

The Civilization of Illiteracy

The cover of the book, an image I designed with the goal of synthesizing what almost 900 pages of text analyze, is self-explanatory (Figure 7).

If the reader of our days sees in this almost 20-year-old image the present of networks, globalization, the digital library, the iPad, or the iPhone (and similar interactive devices), the author can be satisfied. But most important is the realization that this image is about a fundamental change: from a system defined by permanence, continuity, hierarchy, centralism, sequentiality, determinism, and locality, in which any progress was slow in coming (all characteristics of the pre-industrial society leading to industrial society,) to one of rapid change, transitoriness, decentralism, heterogeneity, distributed tasks, globality, parallelism, and discontinuity. Umberto Eco, a colleague I was allowed to call friend, realized the purpose of the book and endorsed it (as he endorsed many colleagues). After arriving in the USA (in 1980), I took note of the fact that in the most effective economy on Earth, the majority of the population was functionally illiterate! But very successful.

The book is the outcome of a dynamic systems-based research of the transition from a society stubbornly pursuing the ideal of literacy against the reality of many literacies – required by the specialization necessarily resulting from continuously mediated forms of work and life – and no form of permanence. It presents the proof that the past (as in past states of an open system) does not inform the present (current states,) and even less the future (possible future states). Many of the ideas in the book slowly came into the cultural discourse, and were so to say "re-authored". A new concept for education in the age of interaction is but one example.

Pericles' *idiotes*, describing those worried only about themselves, inspired the book *Are you Stupid? A Second Revolution might save America from herself*. The outcome of the systems analysis is straightforward: the current situation in the USA (and for that matter in the world) is rather the expression of the failure of politics to be anticipatory. When poll-driven politics succumbs to the reactive mode, every situation looks like a crack that needs patching, even after the bridge collapsed. Those interested in political anticipation (a growing field in Europe) need to be aware of the difference between the two. To this effect, the UNESCO Chairs in Anticipation, an international conference on the subject (Trento, 2015), and a doctoral program in anticipatory engineering (University of Reading, UK) are part of the record. The organizers of the second conference on anticipation (London, November 8–10, 2017) suggested a framework for presenting my views (on anticipation and change). Nothing better can happen to our work than to see it acknowledged, sooner or later, by becoming part of the new consciousness – whether credit for the original ideas is given or not.

A genuine science of the living

A genuine science of the living – not applied physics and chemistry, not even computational models – has to be grounded in the notion of life. So far, Rosen's description, "A material system is an organism if and only if it is closed to efficient causation" – with its implicit reference to the Aristotelian view of causality – is the only attempt at a foundation of a genuine science of the living. Defining life in terms of our ability to know what it is (while we ourselves are part of it) was prompted by Gödel's decidability. Indeed, life is manifest above the threshold of G-complexity, which means, in reference to the human being as observer, in the *undecidable*. Consonant with Uexküll in respect to meaning, and with Elsasser in respect to creativity, my view of life suggests interactivity as the overarching entailment of change. It is always expressed in action. It is the nature of change in the living that entails actions (ranging from long-term adaptive processes to immediate autonomic avoidance of danger). Thus, anticipation becomes definitory of the living. It is always expressed in action preceding change. Actions engage the entirety of the organism (plant or animal). Accordingly, a genuine science of the living can only be holistic.

The realization that physical causality could be a subset of natural causality might entail the need to understand "Nature" beyond Newton's unifying view that aggregates the living and the physical and declares the laws of physics – reflecting God's control over the universe – as universal. Eliminating God from the picture, Darwin's *Origin of Species* (1859) was celebrated as the equivalent of Newton's foundation of physics (*Philosophiae Naturalis Principia Mathematica*, 1687). Natural selection describes the implicit dynamics of the living. It is, of course, of a precision different from that afforded by Newton's equations. In order for the theory of evolution to make sense, it has to refocus away from the determinism everyone wants to see confirmed onto a new understanding, one that integrates non-determinism (which is not the same as randomness!). The refocused view of evolution as driven by anticipation and being non-deterministic could help us better understand it. Some species succeeded against the evolutionary odds; other failed, even when everything within Darwin's theory (and its more modern versions) guaranteed their success.

Determinism, the characteristic causality of physical phenomena, is relevant to the physics of the living. But it returns an incomplete explanation of the changing living. Just to present an example along this line: physical forces (e.g. pulls, compressions and stretching, distortions) applied to a cell can further affect it, probably more than the inherited genetic code does. Taking both physical forces and the genetic code into consideration affords an understanding of cell changes that neither can deliver alone. Non-determinism, describing a relation between cause and effect offering a multitude of possible outcomes, pertains to change as an expression of something being alive. Indeed, changes due to physical forces applied on cells (e.g. a cut or a blow) and genetic processes governing all dynamics are interwoven. There is no way to unequivocally predict whether the cell becomes cancerous or simply divides in a process of self-healing. The living is the domain of "repetition without repetition" (Bernstein), i.e. non-monotonic change. This is a data-supported argument in favor of transcending the machine view characteristic of Cartesian determinism and reductionism.

The question of legitimacy

The question of legitimacy, as it pertains to the anticipatory perspective, transcends the theoretical. It has consequences for the way we conceive of means and methods for maintaining life: the domain of medicine (but not only). To know how the physical changes is to infer from a quantitatively described past state to a future state, under assumptions usually defined as initial conditions (also expressed numerically). To know how the living changes is to integrate inferences from past states with interpretations of the meaning of possible future states. No falling stone will get hurt (not to say die); a falling living being (cat, human being) can get hurt (and even die). The framing of change within the respective consequence is key to understanding their difference. The causality specific to interactions in the physical realm is described in Newtonian laws – action–reaction, in particular. The causality specific to interactions in the living includes, in addition to what Newton's laws describe quantitatively, the *realization of meaning* in connection to the possible future, i.e. anticipation. This explains the variable phase space of the living.

The anticipatory perspective is the alternative – a new frontier in science. But it is not as comfortable as the beaten path of physics and its promise for technology. It took over 200 years (more precisely, since Newton, Descartes, and Laplace) for scientists and scholars to realize that the beaten path at best offers partial answers (often wrong) to the question of what change means in the living. Therefore, one cannot expect abrupt abandonment of the huge investment (time, energy, money, human lives, and the lives of animals used in experiments) in following the wrong path. Against the background of scientific advancement, we can hope for a shorter time for ascertaining a complementary view. We should start by applying it to situations for which physics-based medicine is not adequate. The aging of the world population is only one aspect; the degeneration of the species – expressed in, among other ways, systemic disorders and debilitating spectrum conditions – is probably an even more critical problem. Conditioned by its own reductionist-deterministic theology (cf. arXiv:1612.02491v1), humankind is progressively losing anticipatory abilities (at both the individual and the societal levels).

The irreproducible and undecidable

When in particular domains 80% of published results, from researchers who earned the respect of their peers, proved to be irreproducible, something might be off with the expectation that research, no matter which subject or purpose, is best validated through reproducible experiments. So far, the reproducibility–irreproducibility crisis has encouraged finger-pointing and palliatives (crowd-sourcing is one), but not critical re-evaluation of the means and methods of research.

The crisis of reproducibility, which the American National Academies is examining as well, should not go to waste. It is an opportunity for opening a discussion of the relation between various knowledge domains and the need to adapt research methods to the specific dynamics of the subject that scientists attempt to describe. The worldview according to physics gave way to a multitude of perspectives, sometimes antagonistic, other times complementary. Unfortunately this progress is not yet reflected in the need to transcend the presumptions of knowledge acquisition through experiment, regardless of the particular epistemological condition of change in various domains.

After vitalism was debunked, science gave up the distinction between the living and the non-living. This in itself is significant. Scientists never discard a question because a wrong answer was given. Elsasser's and Rosen's foundational works in defining the living were pretty much ignored at the time they were published. Their respective arguments, quite different in their perspectives, deserve a closer look at this moment of questioning research and validation methods. The vast majority of irreproducible experiments pertain to the living. This in itself is indicative of an inadequacy of what science does in dealing with what is alive. The living is heterogenous, purposeful, and anticipatory; the non-living is homogenous, purpose-free, and reactive. To know is to be aware of distinctions as they pertain to change – especially those of a fundamental nature.

Taking Gödel's concept of decidability (the logic of incompleteness pertinent to axiomatic systems used in arithmetic operations) and applying it to defining knowledge domains is an opportunity. In this view, a subject is decidable if it can be fully and consistently described. But the focus in this alternative view is not on Gödel's rigorous logical proof, as it is on the notion of decidability, extended here from the formal domain to that of reality.

Indeed, physics, astronomy, geology, and knowledge domains where reproducibility is close to 100% represent descriptions that can be complete and consistent. The threshold from the decidable to the undecidable is the so-called *G-complexity* (G for Gödel, obviously). The living, in its unlimited variety of ever-changing forms is G-complex, i.e. characterized by undecidability. As a consequence, to expect experiments involving the living (of interest not only to psychology, but also to the biomedical sciences, not to mention molecular biology, genetics, brain science, etc.) to be reproducible is equivalent to reducing the living to its physical substratum, and biology to physics. Too often, such experiments turn out to be mere instances of conditioning (psychology outperforms every other known discipline in this respect). The outcome is nothing more than testimony to how well the subject was conditioned (the Pavlovian model)! This level of limited understanding of causality is occasionally transcended in modern science (and not only in the quantum mechanics perspective). Back in the 1940s and 1950s, Bernstein, critical of Pavlov's model of reflexes, studied neuro-motorics from a perspective that integrated the goal-oriented expression of human action. Nevertheless, the views he (and others) questioned still dominate.

Mapping from an open system (extending from the cell to the human being) of extreme dynamics to the closed system of the experiment (which by definition is supposed to be decidable) might result in reproducibility; but in the final analysis, it undermines the validity of the findings. More recently, brain activity has become the object of computational modeling – a lucrative opportunity for computer science. There is much to gain from computational models, but their intrinsic limitation stems from the fact that algorithmic computation captures only the deterministic aspects of change. Therefore, the guaranteed reproducibility of computational neuroscience experiments conjures knowledge and validation not about the brain, whose deterministic and non-deterministic aspects complement each other, but about computation.

As impressive as the Human Genome Project was, it is a good example of irreproducible experiments. It was generated under the reductionist assumptions of a blueprint – published as such by *Science* – of *homo sapiens* that does not change over time. The 1000 Genomes Project, aimed at studying variation (initially ignored) is proof of yet another irreproducible experiment. An assumption similar to that of the Human Genome governs the current Connectome project. It will be 10 or 100 times more costly than the Genome Project, but not more adequate in reporting on the infinite variability of the cortex. Windelband's view of nomothetic science – expressed in universally valid laws (such as Newton's laws of mechanics) – and idiographic science – diachronic processes never the same – could as well guide in defining new methods for gaining knowledge peculiar to the living. Gelfand's take on the matter of capturing the peculiar dynamics of life processes point in the same direction: "There is only one thing which is more unreasonable than the unreasonable effectiveness of mathematics in physics, and this is the unreasonable ineffectiveness of mathematics in biology".

Looking forward

I recently watched a video interview with Rosen. (He was talking to Peter Cariani, a young man at that time, who preferred Pattee – a friend of Rosen's – and the deterministic path.) The body suffers, the eyes remained of extreme expression, the mind is alert, but not free of concerns. It was tough for him to realize his own decline of anticipatory performance. We know of his attempt to make anticipation useful: an invention, consulting work, and, to the extent possible, more writing (his handwriting gives away the fast deterioration of motoric skills). The testimony of integrity contains the expression of worry regarding the misuse of the anticipation thought. Indeed, to deserve attention, anticipation has to deliver, but in a responsible manner. Each of the projects carried out with my involvement reflected this awareness. The "aging car" idea (a concept delivered in 2003 to Audi, Ingolstadt) and shortly after that to the Mercedes Research Group (Palo Alto, CA) are examples easy to understand. But also easy to misuse. As we age, our ability to drive a vehicle is affected by decreased anticipation. A machine-learning utility could create the profile of the driver and make sure that the car compensates for what is affected. How to protect this profile of the driver from those who might misuse it is not trivial. But it has to be considered in detail. Of course, from here to the "driverless" car (or any other vehicle), the jump is not really big. Social consequences, however, are huge. In the *AnticipationScope*, we were able to detect Parkinson's disease in pre-onset phase. It is not a cure, but early diagnostics can ease, through behavioral treatment, the adaptation to all that this cruel disease entails. The diagnostic, as useful as it might be, also creates problems for those who might receive it. A responsible anticipation science researcher cannot ignore the danger of "marking" some as prey to legitimate or illegitimate interventions. Interaction computation, as an alternative to Turing computation, augments anticipatory processes (such as in navigation). The association between physiological processes and anticipatory expression is yet another landmark – in the Bernstein tradition – to current attempts at ubiquitous monitoring and all its consequences. An anticipation-informed understanding of human–computer interaction resulted in contributions to interface design. *Pokemon Go* is finally incorporating anticipatory features in the immersive interactive experience. But the moral price of this innovation is also high.

Many other projects are in progress; and if not me, then others will eventually report on them and will make sure that the potential of understanding anticipation systems does not increase the many risks people face. If the years to come will allow, I would love to finish a book on anticipation examined from the complexity threshold of decidability, extended to that of evaluating consequences. Also, one on *A New Foundation for Semiotics*, based on the evidence that anticipation is its underlying justification. We need semiotics because to deal with the possible future is to deal with representations and their meaning. Last but not least, continuing to make the point that change is the ultimate *raison d'être* of all science, a book project on the subject, probably shorter than the report you are reading here, is in the works. The more we know about a subject, the less it takes to share this knowledge with others.

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