AI & Soc
DOI 10.1007/s00146-012-0400-8

25TH ANNIVERSARY VOLUME
A FAUSTIAN EXCHANGE: WHAT IS TO BE HUMAN IN THE ERA OF UBIQUITOUS TECHNOLOGY?

Antecapere ergo sum: what price knowledge?

Mihai Nadin

Received: 10 January 2011 / Accepted: 6 January 2012

Abstract In the age of ubiquitous technology, humans are reshaped through each transaction they are involved in. AI-driven networks, online games, and multisensory interactive environments make up alternate realities. Within such alternate worlds, users are reshaped as deterministic agents. Technology's focus on reducing complexity leads to a human being dependent on prediction-driven machines and behaving like them. Meaning and information are disconnected. Existence is reduced to energy processes. The immense gain in efficiency translates as prosperity. Citizens of advanced economies, hurrying in the rhythm of machine-driven interactions, feel entitled to it. Successful at the price of self-awareness, they no longer know what this means. Happiness and prosperity are not consubstantial. Lack of happiness leads to aggression. This is the image of the world as we see it, no longer looking at each other, eye to eye, but screen to screen. The questions eliminated in the process of transferring responsibility from the individual to machines will inevitably become society's new focus. When the goal is to get everyone to behave like a machine, the Singularity hypothesis becomes self-fulfilling prophecy. If, in addition to having exhausted natural resources, society does not want to end up making the human mind superfluous, it has to seek a better understanding of what makes anticipation possible. As a definitory characteristic of the living, corresponding to its complexity, anticipation can no longer be taken for granted, while every effort is made to reduce complexity for efficiency's sake. Awareness of the processes conducive to its expression in successful human action will position human beings as masters of their destiny, not slaves of their own making. *Antecapere ergo sum* might be the counterclaim to Descartes' *Dubito ergo sum*. To resist being perfected into oblivion, that is, unsustainable prosperity, means to reclaim the knowledge corresponding to higher levels of complexity.

Keywords Anticipation · Complexity · Information · Meaning · Singularity · Transaction

1 Handing ourselves over

The romantic age of computation (coming after the romantic age of machines leading to the Industrial Revolution) produces all kinds of hyperbole: "The universe is a universal computer," (Mitchell 2002); "The universality of computation is the most profound thing in the universe," (Deutsch et al. 1995); "Everything is computation," (Rucker 2005, 2008; inspired by Putnam 1960; "Everything is a program," (not only in the movie *Matrix*, but also in Michael Prescott's blog entry of August 6, 2010). Let's assume that all these pronouncements prove to be correct. Digestion, not unlike dreaming, sexual intercourse, playing violin, planting flowers (or just smelling them), getting drunk or stoned, evolution, you name it, end up being computations. So are, in this scenario, the pleasure of roast leg of lamb, hugging, lawyering, killing (or opposing it), playing games, making art, having a heart attack, or a knee replacement (3D printing, of course). They can be reprogramed as desired. Life turns out to be digital, driven by zeros and ones strung into some control sequences of the matter in which our existence is embodied. Poems, perfumes, memories—all computations. Yes, even memories, including those of a time when the spindle became the metaphor for the revolving heavens

M. Nadin (✉)
Institute for Research in Anticipatory Systems,
University of Texas at Dallas, Richardson, TX, USA
e-mail: nadin@utdallas.edu
URL: www.nadin.ws

Published online: 22 February 2012

(Plato's description), the potter's wheel for describing the shaping of reality from matter (Aristotle), and reality was considered nothing other than a clock (Newton, and others before him), a pneumatic (*pneuma* was Greek for *soul*) or a hydraulic pump (Hippocrates), a steam engine (in the Victorian Age), a switchboard or a network (Von Helmholtz 1878), a game, or even, in Shakespeare's words, "*All the world's a stage /And all the men and women merely players. / They have their exits and entrances.*" (You recognize, of course, the monolog from *As You Like It*.)

Metaphors constantly guided those searching for a path to knowledge—sometimes in the wrong direction. Alchemists were given to the obsession with heat; Freud wanted to explain the unconscious on the basis of hydraulics. Always associating the old and the new, metaphors are adopted by those probing the unknown, or who are under the illusion of doing so. Is there such thing as a final metaphor—as computation, subsuming all previous hypotheses is advanced by its proponents? The hope that humankind's quest for knowledge will continue, even past the age of the obsession with making ourselves superfluous through machines that replace us, might itself be a computation. Between the hard place of anthropomorphism that derives the future from the privileged present of human existence in the universe and the rock of predicting the extinction of the species, so many choices are available. Now that the downloading of brain activity seems so close (Nicolelis and Shuler 2001)—the cognitive *how* of human actions—scientists could even conceive of passing on knowledge to the species that will replace *homo sapiens*.

2 What kind of a doctor was Empedocles?

The only problem with the pronouncements in the opening lines is that if everything is a computation, then nothing is, because we'd have no way to define it, no reference to anything that is different in nature, that is something else. God is the machine (Kelly 2002), Universal Automatism (Wolfram 2002), and pan-computationalism (Jaynes 1957) could even be suspected as the new (or substitute) religions of the information age. Or should it rather be written as *Information* (with a capital I), the *blind*—since it has no meaning associated with it—*divinity* derived from thermodynamics, and which Shannon would have felt embarrassed to set up as the encompassing idol of a time he was so excited about? At the future date at which such a view could prove to be adequate (i.e., confirm the prophecies of the high priests of the secular church of computation), it would be impossible to even contemplate distinctions between the human being and the rest of the world. To be human would prove to be one computation, or several, among others—such as NOT to be human. To give machines responsibility for making choices, whether genuinely human or not, could no longer be a moral or technical choice—as Weizenbaum (1976) implied. Choices would be part of the unfolding process of the universe, containing free will as yet another computation, in line with gravity, space, and time. In the *multiverse* (Everett 1957; Deutsch 2001) of this hypothetical universal computation, to be responsible would be as equally probable as to not be responsible—and simultaneous with each other, like Schrödinger's cat, dead and alive at the same time.

This scenario of yet another singularity (which means inescapable development) seems even more troubling than the one ascertaining that soon computational entities (robots or whatever) will outperform the human being, at least in terms of intelligence, if not more. It is, however, less spectacular than the hypothesis, going back to the psychostatics authors of the eighteenth century who wrote about resurrection by numbers, that we are re-embodiments of past computations (Bostrom 2003). Such previous computational entities "populated" the Earth before the calculation called "human being" was eventually carried out. Some will recall Butler's *Erewhon* (especially the *Book of Machines*) and reassure: Take it easy. If everything, including nature, is part of a computation, and if there is evolution (computational process, of course), we are okay. Whatever is better adapted, or even pre-adapted, will make it. Finally, the more vigilant will call the bluff: What is there to wait for? If everything is computation, then it's been so from the very beginning. The Big Bang—a beginning of sorts—would qualify as an outcome on the Turing infinite tape. Paradoxically, the metaphor of the infinite tape proclaims that there is no beginning and there is no end. Go figure!

Epistemology and gnoseology are connected—we cannot explain the universe as a computation without generating it from a computation that might include the Turing machine as a particular form of a more encompassing computer—let's say, a quantum computer. This pushes the discussion into rather slippery territory: What came first, the bit or the computer? Or even more slippery: the bit or matter? John Archibald Wheeler, famous for his contributions to quantum mechanics, claimed that atoms are made up of bits of information (*Its are from Bits* lecture 1989). To make this claim, Wheeler (as we learn from Davies 2004, p. 10) reverses the "conventional explanatory relationship:"

matter → information → observers

and the associated epistemology of objective knowledge, and proclaims a world that is generated by our observation:

observers → information → matter

Matter itself appears as the outcome of information processes. Hobbes (*De homine*, 1658) suggested that the

physical basis for producing ideas and associations, that is, for acquiring knowledge, was mechanical motions in the head. He, thus, established epistemology in extension of Newton's mechanics. Wheeler's views, as well as those claiming that reality is computation, establish epistemology as a branch of information theory or of computer science, seen as a branch of physics. Instead of Vinge (1993) and Kurzweil (2005), we have a plethora of authors pushing a super-singularity embedded in physics or quantum mechanics. It does not matter whether they can prove it or not, as it did not matter whether anyone has proven that the revolving heavens behave like a spindle, that reality is shaped on a potter's wheel, that existence behaves like a clock ("the key machine of the modern age," according to Mumford), a pneumatic or hydraulic pump, a steam engine, or whatever. These are metaphors, ways to "carry over" what we observe, describe, test for, and imagine. These are reductions, some less drastic than the others. What I am suggesting in these introductory lines can be illustrated bringing up Francis Bacon's (1620) analogy: How do we integrate the views of the "men of experiment"—the ants collecting and using what they find—and those of the "men of dogmas"—the "spiders that make cobwebs out of their own substance?" Bacon was partial to the bee: "It gathers its material from the flowers of the garden and of the field, but transforms and digests it by a power of its own." Of course, the doctrinaires of Universal Computation ("men of dogmas" in Bacon's typology), where Judgment is Calculation and nothing else (exactly what Weizenbaum abhorred), will defend the literal meaning of their description. For them, it is not only a new way of thinking, but a reality. They go way further than cognitive scientists have. One of them, Pylyshyn (1980) complained, "…there has been reluctance to take computation as a literal description of mental activity," (p. 111). Computation becomes a literal description that extends from mental activity to all that exists. Reality is computation. Spreadsheets, the calculations behind rocket launchings or involved in producing MRI "photographs" of our brains and kidneys, or the computation on whose basis hedge fund speculation programs succeed or fail make up our world. So do computer animation, neural networks applications, data mining—the new "gold rush" of our times. This is Plato's *Republic* in its glory.

Empedocles founded the "pneumatic" school of medicine. Some readers will remember who he was; for those who do not, there is *Wikipedia* (supervised by little "Fascistos" who know what's "right" and what's "wrong"), the *ersatz* for individual culture. Or what I would call the wisdom of the supervised crowds. It is the new universal substitute for those who skipped substantive classes in favor of college education in square dancing, gay studies, Latina and Latino poetry, vegetarian cooking, and the like. For Empedocles, *pneuma* was at least as real as computation is for those claiming its universality. But did those who adopted the exploration of human functioning as a pump choose to be treated within pneumatic-based medical care? Or, for that matter, would computation advocates accept treatment within universal computation-based medicine? (At times it seems that we have no choice, but this is a different subject.) The reductionist thought of computationalism is evidently more drastic than that of the spindle, of the potter's wheel, or of the pneumatic pump.

3 Change is more than an energy process

Kevin Kelly (of the provocative "God is the machine") is a journalist; metaphors are his trade. Stephen Wolfram and, even more so, David Deutsch might argue that they refer to literal computation. So did Konrad Zuse (1969), the first to suggest that the universe is a computer, more precisely a cellular automaton. Deutsch, of course, refers to quantum computation. In Deutsch's (1985) own words "I can now state the physical version of the Church-Turing principle: 'Every *finitely* realizable physical system can be perfectly simulated by a universal model computing machine operating by *finite* means'. This formulation is both better defined and more physical than Turing's own way of expressing it." These are not sci-fi writers; they are scientists. For them, as for Wheeler, this is not an issue of naming, labeling, or interpretation. But let's not fall back to the never-ending arguments between Nominalism and Realism. Rather, instead of arguing for one or the other, let's pose the question of identity: How do we define computation? Universal or not, how various pan-computationalists define computation is important in order to understand what they actually ascertain. Indeed, the information contained in the statements they make becomes meaningful (or not) only against the background of the foundation upon which the idea is ascertained. Or is it only a placeholder for whatever describes information processes? Interactions can be described in the language of thermodynamics—if we are interested only in the exchange of energy. Information corresponds to such processes. But in order to understand them, we have to focus on change, that is, information *and* meaning. Essentially, the subject is *change*. Knowledge about a changing world is expressed in the form of *meaningful information* regarding the process we call *change*.

In an unchanging world, equal to itself, in perfect equilibrium, there is no exchange of energy, no entropy, therefore, no information. (Recent research, Del Rio et al. 2011, proves this statement.) Henceforth, there would be no reason to pose questions, and no need to seek and formulate answers. If, *ad absurdum*, there were human beings, or anything else alive in such a world, they would not need knowledge because what stays the same, even in relative

terms, does not prompt any question, and does not require action in order to adapt. For something to become information, a question has to be posed. (This model is inspired by Rosen's 1985 understanding of information.) For the answer to make a difference—"a difference which makes a difference" (Bateson's 2000 definition of information; following MacKay 1969)—it has to be meaningful.

4 Time and change

Thesis: The living emerges as a consequence of dynamics.
Corollary: Time is coextensive with change.

In a non-changing world, there is no time, since there is no information and no meaning. Tautologies are the closest we get in describing a non-changing world. Tautologies describe, *per definitionem*, that which stands identical to itself. The clock stands still in a world devoid of change. (Salvador Dali's metaphor in *The Persistence of Memory*, 1931, and even more in *The Disintegration of the Persistence of Memory*, 1954, helps in visualizing such a world.) With change, time slips in insidiously in the form of an *in-between,* between how things are and how they will be. There is a speed of change, as there is acceleration —both defined in relation to a clock, that is, in relation to intervals. How long it takes for something to change is one aspect of its dynamics. The quantitative aspects (amplitude of change) and the qualitative (what it changes into) are other defining parameters of dynamics.

Knowledge is the offspring of awareness of time. In an unchanging world, there is no need for computation: input and output make up a tautology; they are identical. In such a world, there are no causes, and although things can be complicated—after all, matter is complicated—there is no life. Only above the threshold of complexity characteristic of undecidability, that is, where descriptions of reality result in undecidable formulations (Gödel 1931; Nadin 2010a) is life possible and necessary. Ambiguity, the signature of complexity, holds more information than does the well-defined cause-and-effect chain characteristic of the physical. Indeed, the dynamics of the living is manifest in information processes and in their complementary semiotic processes through which meaning comes to expression. The living, as part of reality, is the awareness of reality. Information is the answer to questions regarding reality. Meaningful information is the answer that guides activity. This pertains to all levels of existence: molecule, cell, gene, and organism. To be meaningful, information has to be more than the record of an observation (Wheeler, cf. Davies 2004): Even a bit (such as the click on the Geiger counter) should mean something (his example: *The atom has decayed*).

In a hurried definition of the origin of life, we can say that change, that is, the dynamics of reality, is its origin. The living is matter endowed with its own clock (or even with several, corresponding to its particular level of complexity). Within the living information and meaning make up integrated communication processes at all its levels (molecule, cell, gene, and organism). While the physical world, to which the living inexorably belongs, can be extremely complicated, the living is couched in complexity (Rosen 1988). This is the specific expression of timeliness. To keep things simple: There is timeliness to reproductive cycles, to birth (creation) and death, to adaptive processes, to metabolism and self-repair—all characteristic of the living. Time and life are consubstantial. Regardless of its particular condition—from the simplest monocell to the human being—the living emerges *from* change. Its very existence results *in* change; that is, the living entails change. The associated information and meaning describing the change makes further change possible. The living embodies the ambiguous record of change of the world in which it unfolds. This is the narration of living. With the human being, this record—our particular narration—becomes its consciousness. Its expression takes place through language. *Mecanœpolis*, Miguel de Unamuno's short story (alluding to Butler's *The Book of Machines*) describes a place empty of human beings, a world where there is no language.

This is not the place to rewrite the making, or self-making, of the world. (So many are hard at work trying to do so, and more recently, some have embarked on trying to make the living from the non-living: synthetic life, SLife (Nadin 2011b). But this is the place for raising questions regarding the need to know, and what we actually know when we produce our science, or hypotheses, declaring all there is to be an expression of physics (quantum mechanics, in particular), or of computation, or of some other particular constructs (usually called *forms of knowledge*). Positing change as the explanation for the necessity of knowledge (i.e., for meaningful information) is a starting point. Regardless of the nature of knowledge, it is a description of whatever the living experiences and tries to understand. Each interaction affords details to the description, producing more information, and eliciting additional interpretations of its meaning.

5 Determinism is confounding

Behind each description—associated with Bacon's ants, spiders, or bees as metaphors for different ways to practice science—lies the oldest known question "Why?" This question is repeated by every child and by every scientist; it is entertained by artists, by philosophers. This is the classic subject of causality or, as Rosen (1991) defined it,

entailment. Descriptions qualified as *deterministic* advance a specific form of causality. They introduce a distinction whose significance cannot be overstated: There is something, called *cause*, that, under given circumstances, prompts something else, called *effect*, to happen. In this construction, the particular form of change associated with determinism is associated with a simple clock that does not allow for simultaneity. The cause precedes the effect exactly through duration—the simplest expression of time, reflecting the perception of day and night. Such descriptions are mappings from the world in which things do not remain the same, but are causally connected. The mappings can be univocally, that is, unequivocally, determined: same cause → same effect; they can be ambivalent—some effects associated with different causes—or they can even be ambiguous—neither cause nor effect can be unequivocally defined. Very long sequences of deterministic descriptions end up being ambiguous. The theory of dynamic systems deals in detail with such sequences. Regardless, all deterministic descriptions are partial representations: reductions of a reality in which many cause-effect sequences, some related to each other, some less obvious in their relation, and some even unrelated, take place quasi-simultaneously in some retraceable time pattern, or in no time pattern (at least not an apparent time pattern). Determinism is convenient but also confounding. Nothing made this more apparent than computation—regardless in which of its many embodiments. Archimedes' call, *δῶς μοι πᾶ στῶ καὶ τὰν γᾶν κινάσω* (sometimes translated as "Give me a fixed point and I will move the world," or "change the world" as some would interpret) corresponds to the epistemological condition of knowledge under the assumptions of determinism, for which the lever is a good metaphor. Since everything, including ourselves, is changing, to know how and even why (the quest for causality) things change influences our existence, including changes in our language; and in the constructs we use to explain how change takes place. After Descartes, the only way to escape this epistemological conundrum is reductionism: focus on one specific aspect and hope for circumstances that make generalizations possible. With the advent of the quantum mechanics construct, there was a hope that reductionism would cease to be the dominant epistemological method in understanding dynamics. It may be that the proponents of the Universal Computer metaphor gave into the hope of transcending reductionism while still holding on to their deterministic views.

6 Future is a faster clock

Change is embedded in the notion of future: In the absence of change, there is no entity called *future*. Time scale, that is, how fast change takes place, leaves its imprint on the awareness of change characteristic of the living. In particular, the human species acquires a sense of the future as it transcends the solely deterministic action-reaction condition of the physical reality. To know is part of the adaptive dynamics of the being. We need to know—in an explicit or implicit manner—in order to adapt to change. That there is a price to knowledge is a relatively late realization. But awareness of this price is expressed constantly. In this respect, Faust, among many other testimonials to this awareness, becomes iconic and exemplifies a long process of epistemological relevance. It is on account of knowledge (explicit or implicit) that human action is much more efficient than any attempt to simulate it. Clark (2008) reported on the difference between the energetic expenditure of a walking robot (Advanced Step in Innovative Mobility, Honda's *Asimo*) and a person: fifteen times higher for the robot. Energetic expenditure in relation to how we move around defines the energy it takes to "carry a unit weight a unit distance." A similar measure can be defined for other actions, such as lifting something, focusing on some distant or close object, etc. Successful dynamics in a deterministic world is expensive. To walk—that is, to actively experience space—is a manifestation of the dynamics of the living. Electromechanical crawling, bending, squatting, flying, etc.—each require a higher energetic expenditure than that of the living performing the same. Human steps are natural; they integrate many components: motoric, cognitive, sensorial, etc. Walking reflects experience, which is another way of saying that it is based on learning, and on awareness of the physical world. It is energetically optimized exactly because awareness of the world allows for movements supported by the descriptions we call *laws of nature.* Specifically: awareness of gravity—not of the law but of its manifestations—is implicit in the walk of human beings and the running of animals. It is probably in this sense that Goethe, in *Faus*t (ll. 682–683), suggests that inheritance is not enough:

> Was du ererbt von deinem Vater hast,
> Erwirb es, um es zu besitzen

What one "inherited from his father," one has to acquire, to actively make his in order to own it. It is a thought impossible to ignore as we discuss what happens when human beings trade their souls for knowledge as illusory as its source. In addition, there is something Darwin called *preadaptation* that explains how walking under changing circumstances (up and down, flat surface, uneven terrain) is performed as though our feet would already know what's next, even though they never trod in the place. To simulate preadaptation, even under the assumption of quantum computation, is to conceive of machines with self-awareness and ability to change as the context changes, even in advance of changes.

7 Was Faust unhappy?

Faust is willing to enter a pact with Mephistopheles for nothing less than knowledge regarding change. This is the case regardless of the rendition—i.e., the initial story of Dr. Johann Georg Faust, astrologer and alchemist, given to black magic; the *Historia von D. Johann Fausten dem weitbeschreyten Zauberer und Schwartzkünstler* (The History of Dr. Johan Faust Notorious Black-magician and Necromancer [sic]) of 1587; or Christopher Marlowe's play (1590)—in which we get to know him. Goethe was aware of (and influenced by) all this, as he was influenced by the *Chronicle of Job*, *The Odyssey*, and other sources relevant to the subject of "What price knowledge?" The knowledge is no longer limited to the "ecological control" of natural walking that makes it elegant and less energy consuming. It involves the ability to explore, adapt, evolve, create—all expressions of knowing the future before the future takes place, and of acting on account of this knowledge (Nadin 1991). It involves preadaptation. This is a shorthand definition of *anticipation*. It is always expressed in action. In a relatively stable world, of allegiance to authority—such as the world described in *Job*—God allows Satan to test his most faithful subject: "Behold, he is in your hand, but don't touch his life." No matter what, Job will remain faithful. Divinity translates into expectations fulfilled. The chronicle celebrates permanence. In the *Odyssey*, change is different in nature: Odysseus experiences it as a traveler. There are many *epreuves*; he is victim of the gods he angers, and of his own desires. He is involved in the game of probability. Warned by Circe about the sirens, he tries to avoid giving in to weakness: "You are to bind me with strong ropes and fasten me upright against the mast." And in *Faust*, finally, the realization that the future is different from all we know. The seductive power of knowing things before they take place, in anticipation, even if the price of this knowledge is the highest one can imagine, drives the well-known exchange: Give me your soul, I will give you access to the future, and thus to pleasures not attainable otherwise. No warning though about the outcome: To know what comes might not make you happy. (The most recent interpretation of *Faust* [Alexandr Sokurov, 2011] is a film trying to tell us that unhappy people are dangerous).

There is determinism, of religious origin, in the story of Job; there is less of it in the *Odyssey*, because free will starts manifesting itself as an important dimension of Odysseus' fighting destiny; and there is a lot of questioning of determinism, and the associated notion of predestination, in Faust. Actually, Faust could conjure the Universal Computer and seek a different pact: I am willing to give up better Judgment for the Calculation that will make the future the present of all my wishes and desires fulfilled.

Of course, in the digital world, there is no need for Mephistopheles, or for God, to allow him to lead Faust astray. This is a service that, in the spirit of quantum mechanics, includes superposition and entanglement. What would Faust pay for the service of being offered the virtual future is a matter of speculation. What do we pay for the service? Faust the real (as legend has it) and Faust the virtual, no matter how far from each other are like they never parted ways: change in the condition of one (even a thought), instantaneously brings up a change in the double (the avatar, one feels like saying). In Goethe's version of Faust (1808), *The Prologue* consists of the famous argument: Is the purpose of theater to please the crowd (and to make money on this account), to seek glory for the actors (the celebrity cult is not a new invention, even if it might be only a computation among many), or to provide a meaningful aesthetic experience that gives the poet the last word? Tradition has it that the actor performing as theater director will reappear after the *Prologue* as God; the one playing the Actor reappears as Mephistopheles, and the actor playing the role of the poet will reappear as Faust. This is already an interpretation. The information—who plays which part—is associated with meaning.

8 Life is a game. Games are life

There are many other versions, inspired by reports about the real person called Dr. Faust. Abbot Trithemius, the Benedictine monk contemporary to Gutenberg, was quite taken by the obsession with the magic of his time; he mentioned Faust, not very kindly, in a letter (dated 1507), and this letter remains one of the references to the actual existence of a Doctor Faust. By 1587, a popular rendition of what developed into the Faust legend made it to print. Christopher Marlowe wrote *The Tragical History of the Life and Death of Dr. Faustus*, first performed in 1594. Goethe, almost 200 years later, started working on a two-part tragedy (published after his death). After that, the floodgates opened. The Faustian Exchange has inspired poems, composers, singers, choreographers, and dancers; it became the subject of academic inquiry, multimedia presentations, and video games. Quite a bit of philosophic speculation accompanied the aesthetic interpretations. It is possible that the first quantum computer will be named FAUST (if the marketing experts will come up with a clever scheme for justifying the acronym).

Goethe's Faust (or Marlowe's) could very well serve as the storyboard for a massively multiplayer online role-playing game (MMORPG or MMOG). It has well-defined levels—readers who played games know what this means—and a very challenging goal: Mephistopheles' wager with God for Faust's soul. Or, to return to our question: What price

knowledge? For Faust, to know is to make possible so many dreams and desires: Faust turned into a handsome young man, Gretchen gets pregnant, the dungeon scene, and Walpurgis night are some examples. For the technology deployed in order to get the world to play the game, the stake is lower: How do you use a deterministic machine—the computer as we know it—distributed all over the world (see diagram) in order to support interactions among players at a level of realism that makes the virtual world indistinguishable from the real? Maybe not yet, but close. Even cancer research (a life-and-death matter) adopted games as a medium for experimentation. Technological performance keeps doubling at a rate even faster than in the one predicted in Moore's Law, so that an avatar-kind of experience of Faust and his adventures in 3D (or of cancerous cells multiplying out of control) is within reach, even on our cell phones. Trivialized or not, the bet on the future, even in the age of fast computation, remains a seductive challenge (Fig. 1).

In the game embodiment, real-time events can be injected into the story. It can be data-mined, like many online games are, for detecting risks to homeland security, to the economy, to the government, or to the health of individuals. Commerce could again profit from spying on the players: What colors do they like? How much risk are they willing to take? What is their betting affordance? AI-driven gaming can compete with real players; ALife could contribute life-like behavior; SLife would sample the DNA of better performers who already identify themselves, on AI-driven social networks, through their ultimate genetic signature. Not the science fiction is significant here, but rather the question of meaning: What does it mean to play Faust, or to play cancer? And don't we all do it—those who read Goethe, and those who don't even read? The game cannot be discarded, as Gounod's opera was not discarded, and as many other renditions (some preposterous) were accepted over time. The question posed, "What does it mean to play the game Faust?" is not different from the question prompted by teaching mathematics, literacy, physics, etc. using the medium called game for research. Idealizing the past is as dangerous as idealizing the present or the future. But so is blind acceptance, including that of pan-computationalism, or any conception of the ultimate—whatever it might be: science, ideology, technology, religion. Even monetizing the game experience: Chinese prisoners forced to play, for money, computer games they do not understand, the youngsters transforming their gaming skills into currency, the seniors filling their time on yet another lottery.

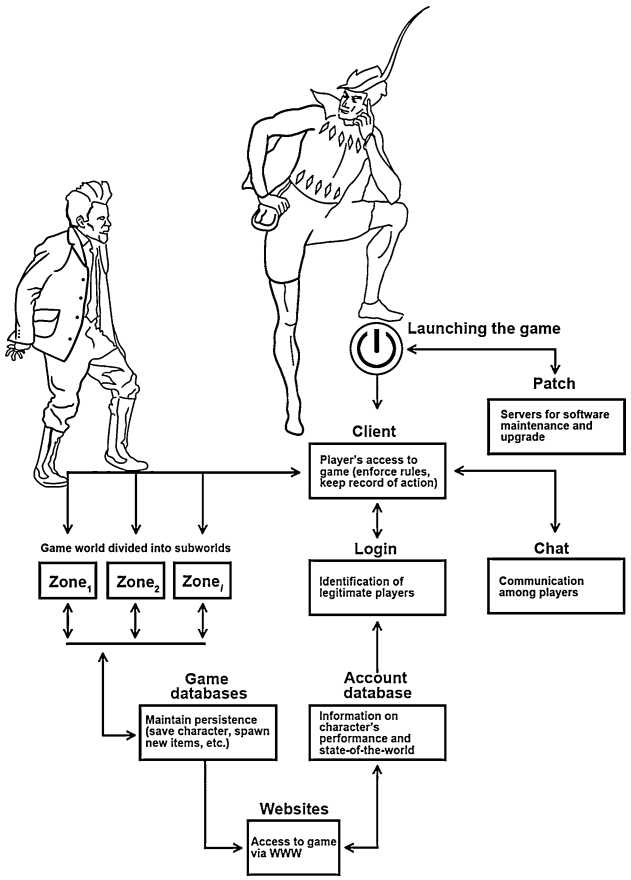

Fig. 1 Playing Faust as a MMORPG game. Is it another Faustian deal?

9 The betting species

To be human in the age of ubiquitous technology is obviously more than playing games (for money or not) on cell phones—even if such games wager knowledge for nothing less than our souls (or what's left of them), or for larger chunks of our lives. The broad philosophical question of whether everything is computation was actually usurped by the commercially inclined to make everything—from work to entertainment and private life—dependent on computers. No reason, of course, to demonize those who successfully monetize the digital. To vilify the temptation to know the future beyond what the tarot card readers say will not help. Asking what the consequences of the new condition of the human being, made even more dependent on technology through the digital, might be or become could start a dialog. Knowledge being often traded for data (not even information), the outcome is a human being for whom time does not extend beyond immediateness. When goals (survival, as well as satisfying ever higher expectations and desires) are nothing but an expression of instincts, instead of projections of values, change is reduced to what aging entails. The wagering animal has no need of transcendence.

Meaningful information comes about from reasoning processes involving knowledge already acquired or in the acquisition process. Therefore, the question of humanness—i.e., is there still a meaning to being human in the world of

substitutes—arises with the same degree of necessity as other questions pertinent to how such a human being is defining itself: Is artificial intelligence (AI) a reachable goal? What does artificial life (ALife) ultimately mean? The same can be asked of synthetic life (SLife, making life from non-life); of virtual reality; of robots supposed to substitute for those who conceived and produced them, and eventually replace them altogether; of computer viruses. Anything else intended to substitute qualities that define the living with properties associated with deterministic processes begs not only questions of feasibility (technological prowess), but also, if not primarily, questions of meaningfulness.

The distinction between the physical and the living brought up the threshold of complexity. In some simpler terms, let us take note of the fact that we can reproduce all physical entities in our universe of living: we make diamonds, synthetic oil, artificial marble, and anything else. The simile of the physical entity is as good as the real. The reproduction of life is a different matter (Nadin 2009). Let's settle for the following observation: For the time being, the simile of life, no matter how successful—and there is nobody left unimpressed, the enthusiasts of technology as well as its skeptics—remains a simile. The meaning of life and the meaning-of-life simile, no matter how realistic and detailed, are fundamentally different. The image in the mirror, be it gold-plated or a computer mirror (virtual life, animation, simulation, etc.), does not know what love is, or what a toothache might be, not to mention the meaning or right and wrong. Or the meaning of *meaning*. And it does not experience the desire to know, the drive to discover. While we know what anticipation means—because there is plenty of evidence expressed in anticipation—we do not (yet) know how to endow the similes of the living with anticipatory characteristics. Otherwise, Stuxnet would have never been discovered (Nadin 2010b, 2011a)!

In the broad context of society, a question looms large and does not forgive those who willfully ignore it: What substitutes what? In practical terms: convenience, prosperity (as relative as it is), pleasure (to increase forever) in exchange for abdicating the responsibility associated with free will, are achieved. Are they real or similes? In a different formulation: Knowledge is what human beings need in order to achieve goals transcending those associated with their instincts, that is, with immediateness. The knowledge supplanted in the Faustian deal—Mephistopheles as computation could be the partner in the deal—would be acquired through anything but human activity. Actually, it would take the form of data streams, to drive machines that do more and more of what our ancestors used to do, or what we ourselves are still doing. Those who came before us were what they did. We are what we do. Will we say of our children, or the next generation, that they are "no longer what they have to do, but expect machines to perform," including thinking for them? The bet is on that this will not be one of the questions they will entertain.

There is, of course, reason to be concerned about the shift from practical experiences defining an epistemological condition reminiscent of Bacon's bees in favor of a category not present in his typology: the wagering, the betting, species. There was always betting in the life of human beings. The most daring mathematics originated from the obsession with beating the odds. Blaise Pascal and Pierre de Fermat, Christian Huygens, Jakob Bernoulli, Abraham de Moivre, Pierre de Laplace, Chebyshev, Markov, von Mises, and Kolmogorov were not necessarily throwing dice for a living, or spinning the roulette wheel, playing blackjack, or betting on lottery drawings. Neither had von Neumann and Morgenstern, with their game theory, intended to make us all winners. They asked serious questions about probability and randomness; they were debunking the notion of luck or the assumption that elections (which are themselves forms of betting) are the expression of democracy. Kenneth Arrow, following Jean-Charles de Borda, Condorcet, Charles Dodgson (better known as Lewis Carroll), is only the more recent celebrated example of this interest in the election process.

Once betting replaces everything else—farming, manufacture, learning, etc.—the species itself is reshaped. We are not only what we do, we are also what we do to ourselves as we put ourselves up for auction and cash the check without knowing how low we valued ourselves. The enormous increase in data production—endless arrays of numbers—acquired through a network of sensors on a scale by far larger than that of human perception of the world, facilitates new means for describing reality. Information reports on changes and guides the processing of data. Information processing, in a variety that continues to diversify, should have afforded humankind predictive means and methods for addressing extreme events, disease, economic, and political instability. Unfortunately, although we have plenty of data and an increased amount of information, we do not pursue *meaningful* information. While on account of partial information we can react ever more rapidly, we are less than successful in understanding the whole, reduced to way too many parts. To be dogmatic about a holistic perspective is not an answer; to acquiesce to the new condition of extreme fragmentation might be consequential beyond the lifespan of the species (our own included). Preadaptation explains flying, hearing, lungs, etc., but also changes the nature of perception (Kauffman 2004, p. 664). Goethe suggested that we all earn what we inherited—an active ownership is always based on becoming a stakeholder to our own destiny.

10 A new marriage license

Equating the attitude toward marriage to a machine with denying gays and lesbians the right to marry, a reporter for *Scientific American* led Sherry Turkle, the MIT psychoanalytically trained psychologist in the business of debunking technology, into defining a so-called "species chauvinism." The subject—marriage to a machine, having sex with a robot, and more of the same—marks only a next step in the computation expressing the infinity of possibilities in the relation between the living and artifacts (Turkle 2011). It comes as no surprise to find in this realm the example of a couple that took care of the family robot (recall the *Tamagotchi*, to whose well-being millions of youngsters, but also adults, committed) while their baby died of starvation and neglect.

For those pursuing the project of making meat labeled as "Born in a cell culture, raised in a vat" (Specter 2011), reductionist thought is easy to spot: You don't need to slaughter an animal in order to get your meat. The entire culture of animal husbandry—animals partaking in the evolution of humankind—is reduced to what meat represents in the human diet. The fact that animals are part of a larger system in which things are connected, and the connections are meaningful, escapes the consideration of the in-vitro meat fanatics. Marrying a robot, or having sex with one, is as reductionist and deterministic as the "carnery" (meat factory) in which muscle cells are expected to become the nutrition of a future devoid of anticipation.

In the age of ubiquitous technology, humans are becoming savvier users, but also "products" of these fascinating technologies. They are reshaped through each action they are involved in. Instead of disappearing behind new content (as McLuhan naively upheld), computers are settling even in human bodies (as chips, intelligent transplants, genetic computation substituting for damaged or aged parts). In the AI-driven networks, there is no distinction between a person and an AI double. Online games, or multi-sensory interactive environments, make up a reality that leads to users reshaped as deterministic agents acting in artificial or even synthetic worlds. Even in matchmaking (in the post-family society, one could wonder what for), you interact less with the one you hope to marry and more with programs (even cheaper than dialog partners in India or some East European country). Alienation aside, reduced attention span is probably the most obvious symptom of the new human becoming dependent on prediction driven ubiquitous technology. On the television game show *Jeopardy*, competitors answer questions, ranging from the insignificant to a vaguely defined popular culture, not so much for the wager as for a spot on TV monitors. Watson, IBM's future super diagnostician for the world, distributed over 900 servers, integrates voice recognition, database management, and advanced data processing. It took the prize because what counts for *Jeopardy*, as it does for American schools, is not knowledge, but large-scale rote memory, reflective of an attention span that eliminates meaning from history. Multitasking—which is actually no-tasking—is yet another characteristic of those growing up dividing their attention until there is nothing left to divide. But most definitory of the process of reshaping the human condition in a context of subservience to technology is the accelerated effort to reduce complexity and the expectation of making the human being behave more and more like a machine. The reduction of complexity might make it easier to cope with faster and deeper reaching change. But it comes at the price of values characteristic of the human being as the locus of predefined information processes, and of meaningful choices.

Returning to metaphors and their associated epistemology: If the world is a game, with many levels, here we are, in the present, at the level of complexity that has been reduced more than ever before, while technological complication has substantially increased. Meaning is clouded by the increased amount of data generated. The individual, educated or not, is subjected to binary choices, behind which the only meaning is "Win or Lose." The data rarely becomes information, and almost never knowledge. It suffices to bring up the most recent extreme events—hurricanes, tsunamis, economic meltdown, political upheavals—to explain what this means. Deutsch (2005), in a TED Global 2005 presentation, made the point that the universe is made of matter, energy, and evidence. He is not wrong in suggesting that the Newtonian laws of gravity, for example, were implicit in the rich amount of evidence previous to their formulation. That evidence was constructed into knowledge (and predictive capabilities) only when the right questions were asked. One day we might as well take note of the fact that cancerous cells, present in every organism, are kept under control by healthy cells. Only when their anticipatory capability declines does cancer take over. But that would imply that we are prepared to acknowledge determinism and non-determinism together.

Today, there is little reason to hope for this or for acknowledging evidence against reductionist tendencies. Menu-driven choices are canned subsets of knowledge standing in for experiences we never shared. Evidence is filtered until it loses even the appearance of pattern. Existence is reduced to energy processes, subject to extremely effective command and control procedures that are more invasive and stealthy than ever. At least within the Western world, the appearance is that the human being is progressively given the illusion of self-determination and freedom of choice. Democracy is replaced by the machine having as input the *well-engineered* "wisdom of the

crowds," expressed in the never-ending effort to poll for the next best bet. Engineered elections, involving computations reaching into personal choices, maintain a veneer of public participation in political life. When the metaphor becomes embodied, reductionist thought, no longer a hypothesis, becomes an unavoidable law: The individual is shaped to achieve machine-like behavior, including self-repair procedures. Programs are customized, driven by data that is collected from the many profiles that users leave behind them as they interact over networks with other users, or with programs "acting" as though they were themselves humans. Conditioning extends to the most intimate aspects of life. On social networks, a second "Us," a version of who we think we are, or want to be acknowledged as, gives the illusion of openness and freedom. Few, if any, realize that under the guise assumed, they give up the most authentic part of what and who they are. They are like the bank robber whose feat was captured on surveillance cameras (CCT), and based on those images apprehended in the shortest time. When faced by the police and shown his face as captured by video surveillance, he seemed shocked. "But the juice was supposed to make me invisible!" He was referring to the myth that if you rub your face with lemon juice, you become invisible to video cameras. I am referring to the promise everyone makes not to share our personal data and to respect privacy, and the freedom to decide whether we want or not be monetized for someone else's profit.

11 A correlation to wish away

Needless to say: Stupidity in the age of intelligent machines correlates with the degree of dependency which society's members conveniently enter into. What many of the people on social networks would never disclose under their recognizable identity is easily spotted by the stealthy procedures deployed under the appearance of protecting identity. Influence is exercised in a manner that family, school, church, or business would never dare to attempt. Profoundly corrupt, Google's "Don't be evil" actually speaks to the obsessive focus on its own interests. The original impetus of a better search engine based on a clever algorithm was fully replaced by the advertising engine, a money-printing machine driven by the billions who search into the space of their ignorance. When the whole world, words, books, streets, landscapes, images, movies, etc. will be finally indexed, the ontology behind it will look like a cemetery, not living knowledge. The virtual does not adapt. The same people who protest (with good reason) when at the airport the TSA gropes and gets them "naked" in their machines, rush to give out on social media even what they really don't know about themselves. Determinism is hammered into the cells of each and every person to the extent that characteristics of the living are overwritten by the functioning of the integrated global world. By our own deliberate or ignorant actions, we are made into a processor in a very large array of a multitude of processors, asked to perform under the silent scrutiny of yet other processors. Individual output is losing its significance, the goal is fast reaction instead of long-term values to be achieved by people who know not only what they want—no limit to wanting—but also why.

The Faustian exchange appears to have taken a new direction: stupidity as the price for prosperity. Even worse: Biologically, the species is past its climax. It is on a descending curve of many degenerative processes. Machines connect better than the members of the new autistic society. But the energetic expenditure of machines is such that, at the time of its highest prosperity (and effectiveness), humankind faces a crisis of sustainability. The spectacular productivity of machines releases people from work for increasing amounts of free time. However, future generations expecting to be rewarded with a higher standard of living just because their parents procreated them will have time, but they will not know what to do with it.

The immense gain in efficiency, on which prosperity is based, is accomplished at the price of diminished self-awareness and even of relative self-destruction. We have it all—whatever we wish—but we don't know what it means. Indeed, when the goal is to get everyone to behave like a machine, the Singularity hypothesis (monetized by Kurzweil) becomes self-fulfilling prophecy. To resist being perfected into oblivion means to reclaim the right to knowledge corresponding to higher levels of complexity, refusing to succumb to data and to the belief that we don't need to care about meaning. Ubiquitous technology makes knowledge meaningless to those using it, since the reason for acquiring knowledge in the first place—what it means to make bread, for example—was canceled by the very existence of such technology: the bread-making machine. That bread is much more than what comes out of such machines, that bread has a richness of meaning and many functions is "reduced" in the exercise. The fact that meat is more than protein, iron, and zinc might be discovered once the first vat-burger is tasted. Nothing against good navigation systems, but discovery is never made at the end of a GPS record of returned data, but rather in defiance of it. What is lost in the process of transferring knowledge to machines is exactly that which defines humankind as the result of change, and the agent of further change, in full awareness of what it means. In the absence of meaning, a nuclear explosion is only data and could as well be the output of a Universal Computer playing the game *Apocalypse*. The downloaded brain activity that underlies kneading dough for bread, or deciding whether it

should have a hard crust or not, does not acquire meaning in the devices that might make the bread of the future. The downloaded brain activity of people involved in natural processes within which animals play more than the role of "meat makers" does not acquire meaning as the nutrients for the vat in which cells are grown are selected. Even playing chess, in which machines outperform the human chess player, to download the brain activity is not sufficient for reconstituting the meaning of the game. Playing with programs is technologically a very respectable example of computer performance. But it is no more meaningful than chatting with "social" programs or marrying a robot. Time, at the scale of history, and culture, as a record of our own history, are compressed to the scale of processing durations. If it lasts beyond 6 s, it is boring.

The questions eliminated in the process of transferring responsibility from the individual to machines ought to become our new focus if, in addition to having exhausted natural resources, we do not want to end up making the human mind superfluous. To revisit Goethe's verses: the human being inherits from a long line of parents. Some of what was inherited was lost since new circumstances of life made so much of what it took to successfully survive and evolve irrelevant. Obviously, the shift from physical effort to mind driven activities had as a result the amazing record of humankind's progress. This is the narration of *homo sapiens*. But it also impacted upon the long-term viability of the species. We can be history sooner than we'd be willing to accept. To only react to the world, instead of uniting reaction and anticipation, is to become like the physical, and to eventually be indistinguishable from it.

In the new context of existence, many questions are articulated regarding the relation to the environment, to sustainability, and to the well-being of the individual and of society at large. One question is addressed rather timidly: Are we on a degenerative course? A variety of forms of degenerative disease cause physicians to worry. The entire spectrum disease catalog is indicative of a lifestyle that goes against maintaining physical and mental abilities at the level at which the individual does not become a social burden. Autistic behavior, clinical or not, is growing. In many ways, autism seems to have become a generalized characteristic of affluent societies. To earn what we inherited means to actively put to good use the natural endowment as well as the knowledge accumulated. Goethe would have probably worried that so much of what is passed from one generation to another is wasted. Indeed, unhappy people endanger themselves and others. And Darwin would have posed questions regarding preadaptation. Programed to behave like machines, we end up with their afflictions and have our pains and discomfort addressed as just another machine breakdown. A better understanding of what makes anticipation a defining characteristic of the living—human or any other living form—will position us as makers of our destiny, not slaves of our own making (Wiener's warning). *Antecapere ergo sum* might be the counterclaim to Descartes' *Dubito ergo sum*.

Acknowledgments In some ways, my first meeting with Joseph Weizenbaum (Interface—Multimediale, Hamburg 1993) was the beginning of this article. Our views on the "digital age" were quite different, but our respective assessments of the impact of the digital on the human being were congruent. Over time, Heinz von Foerster (whom I met on the same occasion), Terry Winograd, Lotfi Zadeh, E.D. Hirsch, Jr., Wolfgang Coy, Hans-Jörg Kreowski, and Solomon Marcus offered me the opportunity to continue the dialog. Even Steven Wolfram agreed to disagree with me on matters of anticipation. Finally, Karamjit Gill gave me the opportunity to put my thoughts, accumulated over some time, to paper. Mike Cooley and Larry Stapleton, the peers who reviewed my paper, thought that it deserves the readers' attention. I owe them my gratitude for suggesting improvements. Of course, antÉ—Institute for Research in Anticipatory Systems at the University of Texas at Dallas and my current host, the Hanse Institute for Advanced Studies, deserve credit for facilitating the work, as does Elvira Nadin, my right hand and my heart. Christian Freksa and Otthein Herzog are my research partners at the Institute, while Reto Weiler and Dorothe Poggel do their best to support my endeavors. For whatever the reader might find fault with, I stand and remain willing to learn from others (and to correct myself as necessary).

References

Bacon F (1620) Novum organum (the new organon) Book 1, aphorism 95 [online]. Available at: http://www.constitution.org/bacon/nov_org.htm. Accessed 16 May 2011

Bateson G (2000) Steps to an ecology of mind: collected essays on anthropology, psychiatry, evolution, and epistemology. University of Chicago Press, Chicago

Bostrom N (2003) Are you living a computer simulation? Philos Q 53 (211):243–255 http://www.simulation-argument.com/simulation.html

Clark A (2008) Supersizing the mind: embodiment, action, and cognitive extension. Oxford University Press, New York

Davies CWP (2004) John Archibald Wheeler and the clash of ideas. In: Barrow JD, Davies CWP, Harper CL (eds) Science and ultimate reality. Cambridge University Press, London, pp 3–24

Del Rio L, Aberg J, Renner R, Dahlsten O, Vedral V (2011) The thermodynamic meaning of negative entropy. Nature 474 (7349):61–63

Deutsch D (1985) Quantum theory, the Church-Turing principle and the universal quantum computer. Proc R Soc Lond Series A, Math Phys Sci 400(1818):97–117

Deutsch D (2001) The structure of the multiverse. Proc R Soc A458 (2028):2911–2923

Deutsch D (2005) Our place in the cosmos [online, posted September 2006]. Lecture, TED Global 2005. http://www.ted.com/talks/david_deutsch_on_our_place_in_the_cosmos.html

Deutsch D, Barenco A, Ekert A (1995) Universality in quantum computation. In: Proceedings: mathematical and physical sciences (8 June) 449:1937, Royal Society Publishing, London, pp 669–677

Everett H (1957) Relative state formulation of quantum mechanics. Rev Mod Phys 29:454–462 (Reprinted in DeWitt BS and Graham N (1973) The many worlds interpretation of quantum mechanics. Princeton University Press, Princeton)

Gödel K (1931) Über formal unenscheidbare sätze der Principa Mathematica und verwandte systeme, Monatshefte für Mathematik und Physik 38:173–198. (The first incompleteness theorem originally appeared as Theorem VI, 1931)
Jaynes ET (1957) Information theory and statistical mechanics. Phys Rev 106(4):620–630
Kauffman S (2004) Autonomous agents. In: Barrow JD, Davies PCW, Harper CL Jr (eds) Science and ultimate reality: quantum theory, cosmology, and complexity. Cambridge University Press, Cambridge
Kelly K (2002) God is the machine, Wired 10.12, December [online] http://www.wired.com/wired/archive/10.12/holytech.html. Accessed 15 May 2011
Kurzweil R (2005) The singularity is near. Viking, New York
MacKay D (1969) Information, mechanism and meaning. MIT Press, Cambridge
Mitchell M (2002) Is the universe a universal computer? Science 298 (5591):65–68
Nadin M (1991) Mind—anticipation and chaos. Belser Presse, Stuttgart
Nadin M (2009) Anticipation and the artificial. Aesthetics, ethics, and synthetic life. Special issue on ethics and aesthetics of technologies—AI & Society (computer science). Springer, London, pp 103–118
Nadin M (2010a) Anticipation and dynamics: Rosen's anticipation in the perspective of time. (Special issue) International Journal of General Systems 39:1 Taylor and Blackwell, London, pp 3–33
Nadin M (2010b) Anticipatory computing: from a high-level theory to hybrid computing implementations. Int J Appl Res Inf Technol Comput (IJARITAC) 1(1):1–27
Nadin M (2011a) Information and semiotic processes. The semiotics of computation. In: Pearson C, Brier S (eds) Cybernetics and human knowing. A journal of second-order cybernetics, autopoiesis and cyber-semiotics, 18:1–2, pp 153–175
Nadin M (2011b) Computation, information, meaning. anticipation and games. Int J Appl Res Inf Tech Comput (IJARITAC) 2(4): 1–26
Nicolelis MAL, Shuler M (2001) Thalamocortical and corticocortical interactions in the somatosensory system. In: Nicolelis MAL (ed) Advances in neural population coding. Progress in brain research, 130, Elsevier Science, Amsterdam, pp 89–110
Prescott M (2010) Everything is a program [online] michaelprescott.typepad.com/michael_prescotts_blog/2010/08/getting-to-the-bottom-of-things.html. Accessed 16 June 2011
Putnam H (1960) Minds and machines. In: Hook S (ed) Dimensions of mind: a symposium. New York University Press, New York. (Reprinted (1964) In: Anderson AR (ed) Minds and machines. Prentice-Hall, Englewood Cliffs pp 43–59)
Pylyshyn Z (1980) The "causal power" of machines. Behav Brain Sci 3:442–444
Rosen R (1985) Organisms as causal systems which are not mechanisms: an essay into the nature of complexity. In: Rosen R (ed) Theoretical biology and complexity: three essays into the natural philosophy of complex systems. Academic Press, Orlando, pp 165–203
Rosen R (1988) Prologue. In: Kelso JAS, Mandell AJ, Shlesinger MF (eds) Dynamic patterns in complex systems. World Scientific, Singapore, pp 3–70
Rosen R (1991) Life itself. Columbia University Press, New York
Rucker R (2005) The lifebox, the seashell, and the soul: what gnarly computation taught me about ultimate reality, the meaning of life, and how to be happy. Thunder's Mouth Press, New York
Rucker R (2008) Everything is alive. Progress of theoretical physics supplement 173:363–370
Sokurov A (2011) Faust. Winner of the Golden Lion Award at the 68th Venice International Film Festival
Specter M (2011) Test-tube burgers, The New Yorker, pp 32–38, 23 May
Turkle S (2011) Alone together: why we expect more from technology and less from each other. Basic Books, New York
Vinge V (1993) The coming technological singularity, Vision-21: interdisciplinary science & engineering in the era of cyberspace. In: Proceedings of a symposium held at NASA Lewis Research Center (NASA Conference Publication CP-10129) http://www-rohan.sdsu.edu/faculty/vinge/misc/singularity.html. Accessed 3 June 2011
Von Helmholtz H (1878) The facts in perception. In: Ewald WB (ed) From Kant to Hilbert: a source book in the foundations of mathematics, vol 2. Oxford University Press, Cambridge 1996, pp 698–726
Weizenbaum J (1976) Computer power and human reason: from judgment to calculation. W. H. Freeman, San Francisco
Wolfram S (2002) A new kind of science. Wolfram Media, Champaign
Zuse K (1969) Rechnender Raum. Friedrich Vieweg & Sohn, Braunschweig. English: calculating space, an MIT Technical Translation Project MAC, MIT, 1970, AZTEC School of Languages, Inc., Cambridge