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Black-Boxing Organisms, Exploiting the Unpredictable: Control Paradigms in Human–Machine Translations

Jutta Weber

... a kind of simultaneous safety with risk, a transcendence over the 'world' in question at the same time that one is somehow inscribed within it, engaged with an autonomous and therefore not fully predictable other. This produces a simultaneous sense of control over the virtual from 'outside' while being 'inside,' controlled by larger and more powerful forces. The result is a controlled simulation of the experience of not being in control; hence, the best of both worlds (Lucy Suchman, 2006, 6).

Introduction

Cybernetics as well as new, behavior-based robotics implicitly or explicitly claims to reach beyond the old linear and mechanical logic of modern science and to develop a new and more complex technoscientific rationality.[1] This shift is celebrated as paradigmatic by technoscientists as well as social scientists and humanities scholars. For some scholars, new technosciences[2] such as robotics and "cybernetics directly thematises the unpredictable liveliness of the world and processes of open-ended becoming" (Pickering, 2002, 430). With this supposed shift in (techno)scientific rationality new approaches and methodologies of

[1] This paper draws on my German paper Vom 'Teufel der Unordnung' zum Engel des Rauschens. Kontroll- und Rationalitätsformen in Mensch-Maschine-Systemen. In: Blätter für Technikgeschichte Heft 66/67, 2004/05

[2] For the concept of technoscience see Weber (2003, 2010) and Nordmann (2004, 2006).

technoscientific research and design[3] but also theoretical work in the social sciences and humanities is supposed to become possible.

Being curious as well as sceptical about this claim of a more complex and inclusive technoscientific rationality, I will analyse *the epistemological and ontological*[4] *foundations of cybernetics and new robotics with regard to the move towards more effective but not necessarily more complex models of human–machine communication*.

My interest in the epistemological and ontological moves and the reconfiguration of the order of knowledge is partly motivated by my suspicion that the celebrated biologically-inspired versions of human–machine relations in new robotics are following reductionist strategies of problem-solving and a politics of translation already known from systems theory and cybernetics:

In the 1930s and 1940s, systems theory and cybernetics developed new epistemological strategies and ontological foundations which made it possible to (dis)solve or at least circumvent the old dispute on vitalism and mechanism (in biology), holism and reductionism (e.g., between the German "Lebensphilosophie"[5] and the natural sciences). Thereby a new science of command and control came into being. Historian of science Maria Osietzki. has shown how the strong interest in the living and the dissolution of the dichotomy of vitalism and mechanism[6] led to a departure from the old mechanic-thermodynamic model of thought with its unsolved epistemological problems, thereby establishing a new order of knowledge that integrated the living with its capacity for self-preservation. Relying on this new model, a much more efficient translation between organisms and machines became possible which interpreted both as "parts of a higher organization" (Osietzki, 2003, 147; translation J.W.).

In my view, a quite similar translation took place *from Good Old-Fashioned Artificial Intelligence (GOFAI) towards New (Embodied, Embedded, BehaviorBased) Robotics* which relies on interdisciplinary knowledge transfer, the use of effective

[3] For example Deleuze and Guattari (1983), Pickering (2002), Law and Urry (2003).

M. Carrier, A. Nordmann (eds.), *Science in the Context of Application*, Boston Studies
in the Philosophy of Science 274, DOI 10.1007/978-90-481-9051-5_24,

[4] In the following I use the term ontology to signify the meta-theoretical core of a theory which contains syntactical structures, ontological options and central semantics. Ontological options lay down what set of things, entities, events or systems (including their ascribed properties) are regarded as existing; see Ritsert (2003), Weber (2005). Ther term ontology here is *not* used in the metaphysical sense of a categorical structure of reality.

[5] Osietzki (2003); Schürmann (2003).

[6] On the controversy about vitalism and mechanism in biology see Keller (1995); Penzlin (2000).

analogies – especially from biology,[7] but also from philosophy, psychology or cognitive science. *My contention is that the recent transformation of the technoscientific rationality in new robotics leads to an integration and reconfiguration of central epistemological and ontological problems prevalent in cybernetics and systems theory – which are closely related to issues of unpredictability, noise, and spontaneity.*

I suggest that cybernetics and systems theory were part of the shift from the classical sciences towards the technosciences,[8] of the configuration of a new technoscientific rationality. The shift from the technoscientific rationality of cybernetics to robotics can be interpreted as the shift from a more static *biocybernetic rationality* towards a more flexible one (robotics). Nevertheless, this new paradigm with its greater flexibility is still committed to traditional conceptions of *technological efficiency and control*. It does not aim or achieve a more comprehensive theoretical understanding or greater representational adequacy – to the contrary. It abandons the value of representation and black boxes traditional epistemic questions and concepts.

In the following I want to work out ontological and epistemological foundations of cybernetics and GOFAI and their transformation by behavior-based robotics. Thereby I will focus on the reconfiguration (and intensification) of human–machine translation, the idea of a new interdisciplinary (meta)science which transforms the mechanical and linear thought of traditional science and the black-boxing of traditional questions and concepts through the shift in epistemological and ontological assumptions.

By analyzing the new ontologies and epistemologies of cybernetics and behaviorbased robotics, I want to contribute to the understanding of the emergence of recent technosciences (Haraway, 1985/1991; Latour, 1987; Nordmann, 2004; Weber, 2003), at the same time differentiating between a static and a dynamic version of biocybernetic rationality.

> So we don't know if the inside of the box, the black box is correct but at least the outputs are very much correct. So it gives some hope that we're not too far away from the real ...
> (from an expert interview with a roboticist)

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[7] The recent interest of roboticists in biology is not primarily motivated by epistemological discussions (e.g., on vitalism versus mechanism) but by the contemporary encompassing scientific and economic success of the life sciences.

[8] On the concept of technoscience see Nordmann (2004, 2007), Age of technoscience. Paper for the group volume of the ZIF research group 2006/07, unpublished; Weber (2003).

System, Black Box, Information & Code: New Ontologies and Processes of Translation

The cybernetic dream of a universal and interdisciplinary science was motivated by the search for new tools and approaches as well as the desire to reorder the modern sciences. The rhetorics of universality provided cybernetics not only with a powerful strategy to support its supremacy in the envisioned new order of disciplines but also with a "new set of funding possibilities" (Bowker, 1993, 123). Cybernetics was supposed to be a "cutting-edge science, which was proving itself in all spheres (physical, social, chemical, political, microbiological ...) and proving the analytic conflation of those spheres." (ibid.) Cybernetics claimed to develop a science working with innovative epistemologies, methodologies and taxonomies that could better grasp the complex relations between diverse fields of knowledge. It was supposed to be a science capable of handling interdisciplinary problems in our complex postmodern world that is characterized by the blurring of diverse ontic realms, the intense interweaving of science, technology, industry and politics as well as the accelerated production of sociotechnical systems, hybrid objects of knowledge and artefacts. Listen to Norbert Wiener's description of the needs and challenges of modern life in the 1950s: "The needs and the complexity of modern life make greater demands on this process of information than ever before, and our press, our museums, our scientific laboratories, our universities, our libraries and textbooks, have been developed to meet the needs of this process. *To live effectively is to live with adequate information*." (Wiener, 1950, 124; my emphasis)

From the 1940s to the 1970s, the universal, interdisciplinary and at the same time multi-layered approach of cybernetics with its many application fields was quite successful in scientific as well as funding terms. Nevertheless, it might have been the lack of homogeneity which led in the long run to a decline of cybernetics as an autonomous field of research and knowledge: "In spite of its important historical role, cybernetics has not really become established as an autonomous discipline. Its practitioners are relatively few, and not very well organized. There are few research departments devoted to the domain, and even fewer academic programs. There are many reasons for this, including the [...] *difficulty of maintaining the coherence of a broad, interdisciplinary field in the wake of the rapid growth of its more specialized and application oriented 'spin-off' disciplines, such as computer science, artificial intelligence, neural networks, and control engineering,..."* (Heylighen and Joslyn, 2001, 4; my emphasis)

The ability to conduct interdisciplinary knowledge transfer, to find effective analogies covering a vast array of meanings and to building bridges between diverse ontic realms were important means for a future universal science that wanted to overcome the differentiation of the sciences. But it seems that exactly this broad approach was the reason for its decline.

But in the beginning, one of the main reasons for the success of cybernetics was exactly its abilities in translation, to find convincing analogies and connections between diverse realms. One of the central ontological groundings is cybernetics' belief "that machines and organisms were behaviourally and in information terms 'the same'" (Bowker, 1993, 110). This was quite an effective way for a tighter coupling of humans and machines than ever before. The universal language of systems theory with its principles of open systems, the concepts of information and communication as well as the new cybernetic epistemology and ontology in general made a comprehensive and universal theory of organization and communication relations in teleological and functional systems possible – applicable on organisms as well as machines.[9]

The literary theorist and science studies scholar Katherine Hayles points towards the central function of analogy in developing these new approaches in cybernetics: "Analogy is not merely an ornament of language but is a powerful conceptual mode that constitutes meaning through relation" (Hayles, 1999, 91). With the help of analogy and new epistemological and ontological foundations, cybernetics is capable of radically questioning the borders between human beings, animals and machines. While *any questions concerning the intrinsic properties of organisms and systems were disregarded,* it became an important part of cybernetic ontology to study the *behavior* of biological and artificial systems as well as the coupling of system and environment.

The interest in the *behavior* of a system is not at least driven by cyberneticians' involvement in military research. For example, during World War II Norbert Wiener tried to develop an anti-aircraft predictor (but never succeeded). He was mainly interested in the prediction of the *behavior* of the enemy's aircraft. To conceptualize the pilot of the bomber and his machine as one entity – a system – made the calculation much easier and the neglect of intrinsic properties necessary.[10] Cybernetics became a tool for the construction of (anti-)systems with analogical behavior (and not only a theory of anything). Fusing humans and machines conceptually means to ascribe at least in principle the possibility of analogical behaviors in humans and machines. As a result, not only the machine, but also *human beings and animals were black-boxed,* de-essentialised and de-naturalized. Philosopher Donna Haraway characterizes this development in the following way: "Any objects or persons can be reasonably thought of in terms of disassembly and reassembly; no 'natural' architectures constrain system design. ... Human beings, like any other component or subsystem, must be localized in a system architecture whose basic modes of operation are probabilistic, statistical. No objects, spaces, or bodies are sacred in themselves; any component can be interfaced with any other if the proper standard, the proper code, can be constructed for processing signals in a common language." (Haraway, 1991, 162p.)

The systems analogy which couples human beings as machines via black-boxing are crucial tools to intensify the translation of humans into machines and vice

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[9] see Haraway (1985/1995); Keller (1995).

[10] See also Galison (1994).

versa. The former so-called intrinsic properties of the entities in question are made invisible by these tools.

While "(e)nergy and matter were the scientific darlings of the nineteenth century." (Wiener, 1950, 128), in the first half of the twentieth century cybernetics shifted the focus of science towards information. In the 1930s the biologist Bertalanffy developed a general systems[11] theory in which all living organisms were thought of as systems based on homeostatic balance. According to that all organisms were able to maintain steady states as well as their structure and identity in the interaction with their environment and to regenerate and reproduce themselves.[12] This systems logic was not only ascribed to single organisms but to systems in general whether they are biological, economic, or social systems.[13]

This idea propels the idea of organic and non-organic entities, of the material and non-material as equally compatible with processes of communication and control. This tendency intensified in the 1950s, when cybernetics more and more used theories and concepts from molecular biology (and vice versa): In his book "The Human Use of Human Beings" Norbert Wiener claims that the physical identity of an organism is not determined by its materiality, but by its form or organization. The latter stabilizes the organism's identity in its ongoing transformation processes. This ontological claim helps to smooth the communication and translation processes between organic and non-organic entities as Wiener believes that in principle there is no difference between the transport of matter or messages. He states that it is (theoretically) possible to send a human being over a telegraph line, even if it is now (and may be forever) impracticable: "To recapitulate: the individuality of the body is that of a flame rather than that of a stone, is that of a form rather than that of a bit of substance. This form can be transmitted or be modified and duplicated, although at present we only know how to duplicate it over a short distance. When one cell divides into two, or when one of the genes which carries our corporeal and mental birthright is split in order to make ready for a reduction division of a germ cell, we have a separation in matter which is conditioned by the power of a pattern of living tissue to duplicate itself. Since this is so, *there is no fundamental absolute line between the types of transmission which we can use for sending a telegram from country to country and the types of transmission which at least are theoretically possible for a living organism such as a human being*." (Wiener, 1950, 109; my emphasis)

In the (bio)cybernetic paradigm, the most important property of organisms are (self)-organization as well as information processing, transformation and transportation. With the rise of the life sciences and especially molecular biology, there is a growing tendency to interpret the organism as a biotic component in a (cybernetic) network. The borders between the physical and the non-physical are

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[11] See Bertalanffy, von (1940); Penzlin (2000).

[12] see Gloy (1995, 244).

[13] see Leps (2000, 614).

getting more pervasive and the organism is understood as a communication system controlled by the genetic code. These ontological foundations are the basis for the new intimate coupling of man and machine embedded in a “movement from an organic, industrial society to a polymorphous, information system” (Haraway, 1991, 161) which is populated by new hybrid, technoscientific objects of knowledge[14] which are redefined as toolboxes consisting of organic or technical respectively biotic components that can be assembled, dis- and re-assembled in a way that is specific for this new techno-rationality.

> There is no need to integrate the human being into the machine, if the machine is already part of the human being. Volker Grassmuck, 1988, 52 (translation J.W.)

Holistic Approaches, The Promises of Analogy and Transdisciplinarity

The cybernetic coupling of man and machine is made possible via the “scientific darlings” of self-organization, information and communication as well as the universal systems approach. Another important mean is the development of an interdisciplinary approach of cybernetics, paradigmatically translated into action by the Macy Conferences[15] in the 1950s, which aims at a non-reductionist and more holistic technoscientific rationality which overcomes the old logic of modern science and is capable of handling the questions of a complex postmodern world. Science studies scholar Andrew Pickering describes this new epistemological approach of cybernetics in the following way: “... there is something philosophically or theoretically pregnant about cybernetics. There is a kind of seductive mystery or glamour that attaches to it. And the origin of this, I think, is that cybernetics is an instantiation of a different paradigm from the one in which most of us grew up – the reductive, linear, Newtonian, paradigm that still characterizes most academic work in the natural and social sciences (and engineering and humanities, too) – ‘the classical sciences’ as Ilya Prigogine and Isabelle Stengers (1984) call them” (Pickering, 2002, 413f). This new technoscience seems to leave science’s representational view from nowhere behind. According to Pickering, the decisive difference between the new (biocybernetic) and classical scientific way of thought lies in its engagement with the real world, in its performativity, and its focus on emergence, the unknown and unpredictable: “cybernetics [...] is all about this shift from epistemology to ontology, from representation to *performativity, agency and emergence*, ...” (Pickering, 2002, 414; my emphasis) The promise and relevance of cybernetics as well as new AI/robotics is seen in its attention towards the liveliness of the world, its openness and its unpredictable behavior.

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[14] see also Latour (1995/1991).

[15] see Hayles (1999).

But why do some believe that this new science is engaged in a particularly profound and illuminating way with the liveliness of the world? Andy Pickering dichotomises representation and performativity by pointing toward a central difference between cybernetics and traditional AI. In his view, cybernetics rests on an intimate coupling of system and environment. With its idea of "autonomy" it gives its artefacts a certain "elbowroom". Heylighen und Joslyn identify this tendency as the cybernetic claim of an (as if) free will of every actor, which is oscillating between intentionality and adaptation [16] : "Perhaps the most fundamental contribution of cybernetics is its explanation of purposiveness, or goal-directed behaviour, an essential characteristic of mind and life, in terms of control and information. Negative feedback control loops which try to achieve and maintain goal states were seen as basic models for the autonomy characteristic of organisms: their behavior, while purposeful, is not strictly determined by either environmental influences or internal dynamical processes. They are in some sense 'independent actors' with a 'free will'." (Heylighen and Joslyn, 2001, 3) While concepts like purpose, behavior and teleology have been under suspect in biology to support vitalism, they change to central features of a new science of communication and control in the animal and machine in cybernetics.

In 1943 the seminal paper "Behavior, Purpose, and Teleology" by Arturo Rosenblueth, Norbert Wiener and Julian Bigelow was published in "Philosophy of Science". It is often interpreted as a kind of birth certificate of US-American cybernetics.[17] Rosenblueth, Wiener and Bigelow conceptualize (human) behavior as the (negative) feedback of errors, of processes of trial and error and as the result of a tight coupling of system and environment. The focus of attention shifts towards the (prediction of) teleological or non-teleological – which means contingent – behavior of systems (black boxes), while the features of organisms are no more of interest. This approach of negative feedback and the concentration on behavior, on the relation of system and environment, of input and output is regarded as part of a new and "holistic" method.

It looks as if cyberneticians tried to develop an *approach that allows them to theorize dynamics and complexity and to translate these into practices of knowledge.* But while they are able to predict dynamic and complex behavior and to combine diverse ontic realms in a new and unknown way, *they loose the possibility to analyse the immanent characteristics of the single systems by reconfiguring entities (inclusive organisms) as black boxes*.

Cybernetics concentrates on the function and classification of the behavior of systems in general. Its openness to the dynamics, complexity and liveliness of the world is motivated by the desire to describe and control the dynamic behavior of

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[16] There are interesting analogies between cybernetic epistemology and ANT concerning the agency of entities resp. agents.

[17] see Stewart (1959/2000), Bowker (1993), Hayles (1999).

organisms and technological systems (for example, weapon systems) which are very difficult to calculate and predict.

The insight of cybernetics is that the control of dynamic systems can't be static or (too) centralized, if one wants to integrate the unknown or even unforeseen in one's calculations. This is also the reason for the cyberneticians' interest in probability and game theory. Cybernetics is not about the exact calculation of behavior but about its probabilistic estimate – at least in the dominant version that was propagated by Norbert Wiener, who was searching for a universal theory of knowledge, order and calculation.[18] And it was primarily Wiener's cybernetic approach which was transported in disciplines such as pedagogy, control engineering, politics, and sociology. According to Wiener, noise – the disruption of communication – was associated with entropy, decay and death.

While cybernetics enabled the control of (more) dynamic systems and an estimation of systems' behaviour, it is highly questionable to identify this approach with an interest in the "unpredictable liveliness of the world and processes of openended becoming". The cybernetic interest according to Pickering is a very *specific* and reductionist kind of interest in performativity which rests on the calculus of probabilities and the systematization of dis- and reassembling (trial and error).

Symbol-Processing AI, Philosophy and Behavior-Based Robotics

In the 1970s and 1980s cybernetics disappeared as an independent, autonomous field of knowledge and it lost its relevance in the field of Artificial Intelligence (AI) already in the late 1960s. At this time, the symbol processing approach of AI won over the more biological-oriented approaches of cybernetics and early connectionism.[19]

Traditional AI is predominated by classical mathematics and formal logics, while biology and neurophysiology didn't play a role in AI research. The latter is dominated by the paradigm of information processing in which intelligence, the brain and the calculation of symbols is equated. Mental processes – identified with cognition or even intelligence in general – were more or less interpreted as the processing of calculations equated with algorithms. Alan Newell and Herbert Simon (1976) developed the well-known hypothesis of the "physical-symbol-system" which stated that "the processing of symbols, which are necessarily based upon a physical system, is sufficient to model and produce intelligence, if the rules

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[18] For the differences in the epistemological approaches of Wiener and von Neumann see Lenhard (2007).

[19] Think for example of Rosenblatt's neuron-inspired learning device "perceptron" which was radically critised by Marvin Minsky and Seymour Papert (1969). The success of their critique was one of the reasons for the following dominance of traditional AI until the mid 1980s (Pfeifer and Scheier, 1999).

for processing symbols and for the physical machine are powerful enough. In addition, they argued that the rules of the physical machine ‘computer’ dispose of this power. These ideas explain why the representation of knowledge, i.e., *the adequate modelling of the world via symbols and logical inferring* [...] have played, and continue to play such a prominent role in this research paradigm” (Christaller et al., 2001, 66; my translation and emphasis).

This kind of modelling abstracts from all physical and material aspects. The assumption is predominant that mental processes can emerge regardless of the physical system. Embodiment is irrelevant for GOFAI. The internal processing of symbols and the representation of knowledge are regarded as the distinctive features of intelligence. Accordingly, robots are more or less understood as mobile computers. They were equipped with a few sensors and actuators to make some environmental information available, but the main focus was on internal processing, representation and *plan-based* action on the basis of pre-programmed “knowledge”.

In the 1970s and 1980s, AI researchers believed that decision making follows precise rules. As Lucy Suchman formulated in her critique of traditional AI: “The logical form of plans makes them attractive for the purpose of constructing a computational model of action, ... ” (Suchman, 1987, ix)

Given the precondition, traditional AI assumed that cognitive processes could be formalized and mechanized through expert systems which contained these rules and the help of databases with experts´knowledge and (decisions). After some years of research it became evident that patterns of human behavior are much more complex and dynamic – as many critics argued before: “I will argue that all activity, even the most analytic, is fundamentally concrete and embodied” (Suchman, 1987, vii). As knowledge is related to experience, which mostly implies tacit knowledge beyond precise rules, it cannot be (easily) extracted and abstracted and used in a different context. Difficulties and unsolved problems were not only dominant in the field of expert systems, but also in robotics. After decades of research, AI could not present much progress in such fundamental research areas such as navigation, speech or object recognition. The robots were very prone to any kind of disturbances and noise and couldn’t agitate properly in real world systems (think, for example, of walking, climbing stairs, moving on rough underground, etc.). Despite the ambitious visions of early AI, many of its projects seem to be at least impracticable. Rolf Pfeifer, head of the AI laboratory at ETH in Zurich (Switzerland) and his colleague Christian Scheier describe this situation in their book “Understanding Intelligence” (1999) in the following way: “... we began to run into fundamental problems with artificial intelligence. In the mid-1980s we had already been working with expert systems for a number of years. Over time we realized, as did many others, that the technology did not fulfil its promises. Accomplishing what we proposed turned out to be much harder than expected: Only a very few of the projects we undertook ended up with systems that could be used in everyday routine practice. *The problems were not simply of practical* *nature, they were somehow insurmountable*." (Pfeifer and Scheier, 1999, xviii; my emphasis)

While symbol processing systems such as chess computers or industrial robots with clear defined tasks which operated in static, in-door environments were quite successful, any systems that should cope with non-planned behavior and react in real-time to an unknown environment didn't work properly – even after one decade of research. Considering the limitations of GOFAI, more and more roboticists reoriented themselves towards biologically-inspired approaches such as artificial life and connectionism. They distanced themselves more and more from the information processing perspective and its favour for formal logic and mathematics. Biological concepts such as emergence[20] or life got more and more prominent, while old concepts such as representation and the quantitative understanding of information were questioned. Katherine Hayles describes this situation in an illustrating anecdote: "[...] researchers assumed that artificial intelligence should be modelled on conscious human thought. A robot moving across a room, for example, should have available a representation of the room and the means to calculate each move so as to map it onto the representation. [Today's director of the MIT AI Lab, Rodney; JW] Brooks believed this top-down approach was much too limiting. He saw the approach in action with a room-crossing robot designed by his friend [...] Hans Moravec. The robot required heavy computational power and a strategy that took hours to implement, for each time it made a move, it would stop, figure out where it was, and then calculate the next move. Meanwhile, if anyone entered the room it was in the process of navigating, it would be hopelessly thrown off and forced to begin again. Brooks figured that a cockroach could not possibly have as much computational power on board as the robot, yet it could accomplish the same task in a fraction of the time. The problem, as Brooks saw it, was the assumption that a robot had to operate from a representation of the world." (Hayles, 2003, 101)

Brooks (2002) was influenced by the cybernetician and neurologist William Grey Walter who built his famous "tortoises" Elsie and Elmer in the 1940s. These two small, animal-like robots were based on a tight coupling of system and environment and able to explore their environment, to search for light sources as well as to recharge autonomously their batteries. Central principles of these electro-mechanical tortoises beside autonomy were self-regulation (feedback) and spontaneity. They functioned without central representation (of their world). Putting up Grey Walter's ideas from the 1940s, Brooks claimed that *intelligence doesn't need central representation* and that the world would be its own best model.[21] This approach does not only rediscover principles and theorems of

[20] There is no common understanding or even acceptance of the concept of emergence by the AI and AL community – despite or may be because of the central function of this concept; see Emmeche (1994); Langton (1996), Cordis (2000), Christaller et al. (2001).

[21] Brooks (1986); Brooks (2002).

cybernetics, but also draws explicitly on the philosophical critique of symbol-grounded AI. Since the 1970s, philosophers such as Hubert Dreyfus and Barbara Becker as well as science studies scholars like Lucy Suchman or Harry Collins[22] criticized AI's functionalist concept of intelligence for its lack of embodiment, materiality, situatedness and embeddedness. For example, in the 1970s the US-American phenomenologist Hubert Dreyfus challenged the reductionism of AI and its Cartesian separation of body and mind in his well-known book "What Computers Can't do" (1973). He profoundly challenged the idea that cognition should be nothing more than the simple and passive input of information. For him, the body is not an obstacle for, but a constitutive element of cognition. He regards the interaction with the environment and the sensual, bodily experience – the embodied, sensory input of information as roboticists call it – as essential for cognition.

It is amazing that embodiment became a distinctive feature of the new behaviorbased robotics. It is increasingly regarded as a central condition of intelligent systems. In his memo of 1986, the roboticist Rodney Brooks uses the philosophical critique of Hubert Dreyfus to argue for a new and embodied robotics that relies on a tight coupling of system and environment and leaves behind pure simulation and the artificial impoverished toy worlds of GOFAI.

But it is not by chance and not only due to his professional background that Rodney Brooks stresses his solely technical interest in solving the problem: "In this note we use a technical rather than philosophical argument that machines must indeed have a rich background of experience of being if they are to achieve human level intelligence. Unlike Dreyfus however, we conclude that artificially intelligent behavior is achievable with computers without the aid of holograms, resonance, *or other holistic techniques*. Rather, by adopting an incremental construction approach, progress towards this goal can be expected soon. (Naturally, the author and his students are currently following this enlightened path.)" (Brooks, 1986, 1; my emphasis).

In the paper it becomes obvious that the path from GOFAI towards new robotics leads towards the design of new ways to model and to control robots and technical systems, respectively. This approach is not (mainly) about a better understanding of intelligence, of how the mind works and the relation between representation and performance but about building systems and mobile computers, in particular that are capable of interacting with the world – in one way or the other.

New AI now tries to build embodied systems. The construction of these systems is inspired by biology and "its natural principles" and works "bottom-up". Only mobile and embodied agents that adapt themselves to the environment are seen as capable of managing real-time interaction with the environment, navigation and

[22] Becker (1992); Dreyfus (1972); Suchman (1987).

object identification.[23] They regard embodied, autonomous and mobile systems as the future of intelligent systems.

The interest in bottom-up approaches can be seen as part of their search for alternative methods and approaches. A roboticists described his view of the necessity of new methods and approaches in an expert interview[24] in the following way: "I believe, that in biological contexts people are still too much fixated on the world view of the physical sciences, as it originated in the mechanistic time, especially concerning exactness and so on, ..., rigid organization [of their research; J.W.], or causality, mono-causality. .... I think this is not adequate in this field [of research; J.W.] and – as one can see on other levels as well – in ecology or in research of the biosphere. What is really important is to understand the boundary conditions, under which certain processes are possible. And I am not sure on which level it will be possible to understand these processes at all. I am not sure whether this knowledge will be necessary in detail, but it is for sure important to understand under which conditions what kind of processes are possible. I think we will not get much further with regard to living systems. At least in my view it would be a quite demanding goal to achieve this. ... *The classical world view of the physical science is much too narrow to understand the phenomenon of the living world. And the level on which one can comprehend them is for sure one beyond the mono-causal, analytic, reductionist view, but at the same time it is not about holism, but something has to be developed which goes beyond that and encloses both parts."* (from an expert interview with a roboticist; my translation and emphasis)

The questioning of the body-mind dualism is part of this quest for an alternative approach. For example, roboticists Kerstin Dautenhahn and Thomas Christaller (1997) claim that the relation of cognition and the physical constitution of a system must be understood not as independent from each other but as a tight feedback coupling. [25] This stance with its critique of Cartesian dualism became also prominent in some approaches of brain research. Think for example of the well-known neurologist Antonio Damasio who claimed that embodiment is a central condition for human intelligence: "(1) The human brain and the rest of the body constitute an indissociable organism, integrated by means of mutually interactive biochemical and neural regulatory circuits ... (2) The organism interacts with the environment as an ensemble: the interaction is neither of the body alone nor of the brain alone; (3) The physiological operations that we call mind are derived from

[23] see also Christaller (1998, 106).

[24] I conducted these (and other) expert inverviews with Artificial Life reasarchers and roboticists in the USA and Germany during the research project '*Mathematik des Lebens – Konstitution und Geschlechtscodierung eines neuen Lebensbegriffs durch die Artificial Life-Forschung* ' (The Mathematics of Life – Constitution and Gendering of a New Concept of Life in Artifiical Life Research') at the Department of History, Technical University of Braunschweig, 2001–2003.

[25] see Christaller et al. (2001, 84).

the structural and functional ensemble rather than from the brain alone ...” (Damasio, 2000, xvif) While he is not challenging the hierarchical order between intelligence and the body, between the brain and “the rest of the body”, he advocates their intimate entanglement.

Some researchers of new AI put the values of science even more radically into question by abandoning – at least partly – its claim to “model the world without contradictions in an objective and complete way” (Christaller et al., 2001, 72; my translation). This epistemological stance might be the logical consequence of an approach that favors embodiment, situatedness and embeddedness.

This epistemological stance is different from that which dominated traditional AI, mathematics, cognitive science as well as philosophy. The mathematics which is now on the agenda, is the statistically-based mathematics of nonlinear dynamics.

> the real thing is: how do we get spontaneous creation of surprising things (from an expert interview with a roboticist)

Biological Machines: Autonomy, Adaptation and Trial and Error

New robotics – influenced by cybernetics and artificial life research – strives for artificial intelligent systems that operate autonomously in open and complex environments.[26] Biological processes are regarded as the decisive conditions for intelligent behavior instead of precise calculation or knowledge representation. Embodiment, situatedness, adaptation, autonomy, system-environment interaction, learning and self-reproduction[27] are seen as the central features of intelligence. Accordingly new approaches in robotics emerge such as behavior-based robotics,[28] evolutionary[29] or situated robotics,[30] “Embodied Artificial Intelligence”[31] or autonomous intelligent systems.[32]

By approaching biology, the researchers hope not only for a better understanding of living systems but for the emergence of new, successful ideas concerning the construction of software as well as hardware for artificial systems. A researcher describes this move in the following way: “a direction we are trying to go is to get closer and closer to biology. In the sense that we are abandoning a lot of conventional electronics or conventional circuits because we think that it is already too much constrained. It doesn’t have space for reactive autocatalytic

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[26] see Becker (2000).

[27] Boden (1996), Christaller (1998, 2001), Brooks (2002); Pfeifer (2001).

[28] Brooks (1986); Christaller et al. (2001).

[29] Husbands and Meyer (1998); Nolfi and Floreano (2000).

[30] Steels and Brooks (1994).

[31] Pfeifer and Scheier (1999); Brooks (1999), Pfeifer (2001).

[32] For example “Autonomous Systems” is the name of the research unit on behavior-based robotics of the Fraunhofer-Institute at St. Augustin (Bonn, Germany).

properties where you get new matters coming out. So, it is maybe *to go back to the biological basis of real life and try to put it under different conditions*, try to expose it to different types of experiences or try to direct evolution in different ways. And try to see what are the possible alternative mechanisms that you get out of it." (from an expert interview with a robocist)

Differing from traditional AI, new robotics is focusing on the intrinsic properties of the physical quality of embodied intelligent systems. Researchers hope for new materials that might support emergent effects. The development of new combinations of materials – such as organic (neuronal) tissue and chips – is regarded as promising for the production of new, more flexible and intelligent artefacts. Today, many roboticists are convinced that it is important to build artificial systems out of the right material because this can – for example – help to optimise their energy
efficiency or to simplify their control mechanisms.[33]

The principle of "bottom-up" is another important slogan, if not magical incantation of cybernetics and especially new robotics. It builds on the old idea that the whole might be more than the sum of its parts. What else expresses the idea of emergence as something that is triggered by the multi-layered interplay of many modules or programs? Its rests on the condition that intelligence is the product of the system-environment coupling and that organisms in general function on the basis of a huge number of very loosely-coupled parallel processes. Consequently new robotics breaks down the behavior of the system into small modules, in so-called reflexes based on the principle of stimulus and reaction or sensory-motor feedback circuits (such as e.g., the avoidance of obstacles or the search for a source of food/energy, etc.). Rodney Brooks famous "subsumption architecture" is an architecture for autonomous robots, in which modules can be implemented independently to enable their mutual interaction. To reduce symbol processing as far as possible, sensory and motor signals get short-circuited to ensure a tight coupling of system and environment and to support emergent behavior. Researchers hope that this might provide a basis for the "evolution" of unexpected, not pre-programmed behavior. This behavior is used as a central resource to evoke new intelligent behaviour which can be analysed via post-processing. These new approaches and research strategies are often labelled as an inclusion of *spontaneity, versatility and shape-shifting* into the research process and new properties of the now *biologically-inspired* systems. In a way, unpredictability, spontaneity, versatility and shape-shifting become essentials parts of the leitmotif of this new techno-rationality. It contains the *vision of the construction of self-adapting, evolving, living machines that 'outgrow' their programming and which develop their own categories, language and other sophisticated features which are characteristic of autonomous systems in the literary sense of the word*.

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[33] Pfeifer (2001).

> Contrary to the expectation, that the on/off-position of a switch is a concrete, stabile phenomenon of information, it is a very fragile thing. Endlessly is the danger that it is engulfed by the noise of the channel. This enemy of information, >the wild animal<, is permanently on the lookout to destroy signals" (Volker Grassmuck, 1988, 45 (my translation)).

On the Devil of Disorder and the Angel of Noise

Since its very beginning, cybernetics and Artificial Intelligence were very effective and effectful in telling powerful salvation as well as apocalyptic stories about their research fields while "real" successes in technical terms were often missing. It is true, that at least robotics made considerable progress in terms of more smoothly and flexibly moving robots, climbing up stairs, dancing etc. The same could be said about the cooperation of robots with their environment. But still many basic capabilities in the field of navigation, object and speech recognition, complexity (scaling-up) etc. are missing.

Against this background, the new attention on contingency, trial and error as well as tinkering methods and their hasty identification with spontaneity, versatility, and the living could be interpreted as another smart salvation story and clever research strategy to promote the interest in one's own research, to help its funding and to secure the attention of other researchers and of the media.

Andrew Pickering perpetuates these semantic strategies by describing the ontology of cybernetics as a pure thematization of the living which is absolutely different from classical science: "My suggestion is that cybernetics grabs onto the world differently from the classical sciences. While the latter seek to pin the world down in timeless representations, *cybernetics directly thematises the unpredictable liveliness of the world and processes of open-ended becoming*. [...] [I]t is as if the cyberneticians have lived in a different world from the classical scientists." (Pickering, 2002, 10; my emphasis) Pickering sketches a very similar picture of behavior-based, autonomous robotics: "Hard-line autonomous robotics is deeply anti-representational. It wants to build robots that are always in the thick of things – essentially embodied, operating on inputs from the world, transforming them into outputs, monitoring what comes back, adjusting outputs again, and so on – *and all of this without the existence of any abstract, formal, detached representation of the world* in which the robot lives. *An exemplification of the dance of agency itself*." (Pickering, 2002, 10f; my emphasis)

This romantic and over-optimistic description of cybernetics as well as new robotics is grounded in their attention on contingency, trial and error, the surplus of the living as well as the method of tinkering. The latter is a more or less systematically performed way of combining modules in a bottom-up way, of trying out which parts might fit to each other and what the outcome of the interaction of these parts might be. Tinkering – now interpreted as a genuine method of nature herself[34] – is seen as an important tool to bring emergent processes into being.

Pickering is too rash when he ascribes cybernetics an unlimited interest in the unpredictable and claims their systematic usage of tinkering and trial and error. The idea of operating at the edge of order and chaos as well as that of a systematic production of unexpected processes seems to be more a product of the theory of dynamic systems, of chaos theory and a certain version of self-organization theory (like e.g., autopoiesis theory) which understands self-organization as a dynamic (re-) production of the internal order of a system and as a “springboard to emergence” (Hayles, 1999, 11). Accordingly, Peter Galison (1994) and Andrew Pickering (1998) himself stress that Norbert Wiener regarded surprise, contingency and noise as the source of disorder and uncontrollability.

To clarify this point: In the 1940s Norbert Wiener developed an >Antiaircraft (AA) predictor<, a planned air defence system, that filtered the irregularities of the zigzag path of an enemy airplane to track its future position and thereby enabling one to shoot down the plane despite the delay of the air defence missile. The unexpected, surprise, chance and noise are the “natural” enemies in a (military) research project that wants to calculate a dynamic human–machine system: “It [the antiaircraft predictor; JW] lived in real time, but always looking backwards to extract a trend that it could project in the future, and, in extracting that trend, chance (chaos, noise, fluctuation) was the enemy, a confusing disturbance that one had to struggle to counteract, mathematically and technologically.”(Pickering, 1998, 5)

Pickering and Galison stress that Norbert Wiener regards disorganization, chance and noise as the arch enemy, as the source of disorder and unpredictability.[35] Wiener writes in “Human Use of Human Beings”: “The scientist is always working to discover the order and organization of the universe, and is thus playing a game against the arch enemy, disorganization.” (Wiener, 1950, 35) Galison comments: “Cybernetics, that science-as-steersman, made an angel of control and a devil of disorder. ... But perhaps disorganization, noise and uncontrollability are not the greatest disasters to befall us. Perhaps our calamities are build largely from our efforts at superorganization, silence, and control.” (Galison, 1994, 266)

Unpredictability, *emergence and noise have become the ‘angels’ of behaviorbased robotics today. According to this new techno-rationality order emerges out of chance, out of the unpredictable, dynamic and multiple*

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[34] see Jacob (1977).

[35] Pickering claims that the early British cyberneticians such as Ashby, Beer, Pask and Walter, were those who engaged themselves with the unpredictable, the surprise and the unforeseen, while Norbert Wiener built on more total visions of communication and control. In this paper I concentrate on the work of Norbert Wiener because he seems to be the key figure in cybernetics in the midst of twentieth century on the one hand. On the other hand he was also very successful in translating his approach into other disciplines.

combination of simple processes and clever strategies of trial and error. These processes are not instantiations of the living, but by working with repetition and difference, relying on the calculus of probabilities, sometimes results in something new and productive which can be exploited for improving human–machine systems. Relying on emergent processes and the production of the unexpected (probability) does not mean to abandon the demand on controlling nature as Peter Galison and others had hoped for. It is the other way round: *This new science – romanticized by Pickering and some of its own proponents – tries to exploit technically dynamic and complex processes that cybernetics avoided. Spontaneity and the so-called surplus of the living – which was regarded for a long time as the non-exploitable – are getting more and more integrated via tinkering, methods of trial and error, postprocessing etc. (and modern and increasingly fast computers) in this new bottom-up technique of control*. A roboticist describes this approach in the following way: "if non-linear systems are interacting, than we do not have any theory which can predict what might be the outcome of such an interaction. I bet that with the help of evolution there might emerge cognitive processes – whatever that means. ... Under which conditions might it be possible that emergence happens? What are the necessary boundary conditions for such a process? It is not possible to let somehow something self-organize and then there will be emergent processes. That is how people often picture it. *I am sure there are boundary conditions under which emergence can become possible and others when it will not become possible.* If it will happen under the right conditions – that is another question." (from an expert interview with a roboticist)

This new approach is centered on the *determination of optimal boundary conditions to bring emergent processes into being, while ignoring the intrinsic properties of organisms and refraining from the objective description of universal laws. Evolution via tinkering, the processes of trial and error are the main tools to help the construction of complex dynamic and therefore intelligent systems, which are beyond the analysis and control of the classical sciences.* These processes and methods are inspired by biology and the theory of dynamic systems. The use of biology (and especially ethology and theoretical biology) is justified – as cybernetics already did 40 years ago – with the gain of genuine valuable knowledge for biology itself, but also by the usefulness of biology as a test bed for engineering and robotics: An engineer pictures this two-fold task in the following way: "So, if you're expecting biology to provide this template for engineering, it just isn't going to, but it can provide a challenge [...], for engineering technology that is very analogous and potentially powerful. So [...], I'm not doing it because I expect to learn specific things that I can carry out in engineering, I'm doing it [...] primarily to help the biologists and primarily trying to build tools that will help biology and medicine. Secondarily I'm trying to create a test bed for a general set of tools for studying complex networks that will be critical in our engineering infrastructure. So that's a secondary issue and very, very casually is any hope that specific principles will come out of biology that will be relevant, that'll be nice but I think betting on that would be a mistake" (from an expert interview with an Artificial Life researcher)

At the heart of this new science lies the search for the proper boundary conditions which will enable to trigger emergent processes. The main belief is that there are at least some central principles of organization in complex dynamic systems – let them be organic or non-organic. *While the analytical approach breaks down its object in single parts to analyze them, this new techno-rationality builds on (re-) combining different modules in nearly endless repetition to stimulate the emergence of more complex behaviors and systems*.[36] *This means an inversion of the analytical approach.* The contemporary science of communication and control looks forward instead of behind.

The logic of research centers on the emergence of the unexpected (by tinkering and testing what might work). It searches for specific conditions so that it can foster processes of emergence and to open up possibilities which allow the exploitation of surplus processes in a technical way.

These processes are identified much too rashly with the openness of the living, creativity and the unknown – features which were for a long time regarded as the specific property of human beings or organic systems, respectively. Now they are effectfully ascribed to biological and technological processes. Galison hoped for noise, chaos and chance as potential remedies against the control mania of cybernetics. But now it seems that they are transformed into effective research strategies of systematized tinkering, postprocessing and genetic programming. Thereby they have become productive means to ensure new ways of control and to construct efficient artefacts on the basis of a comprehensive systemic biocybernetic techno-rationality. The Augustinian devil of noise and chaos, which was fought by Wiener, has changed its role. It is advanced to the position of the angel in biologically-inspired and behavior-based robotics.

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[36] See Hayles (1999) and Weber (2003).

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