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The Embodied Mind

On Computational, Evolutionary, and Philosophical Interpretations of Cognition

Abstract

Modern cognitive science cannot be understood without recent developments in computer science, artificial intelligence (AI), robotics, neuroscience, biology, linguistics, and psychology. Classic analytic philosophy as well as traditional AI assumed that all kinds of knowledge must eplicitly be represented by formal or programming languages. This assumption is in contradiction to recent insights into the biology of evolution and developmental psychology of the human organism. Most of our knowledge is implicit and unconscious. It is not formally represented, but embodied knowledge which is learnt by doing and understood by bodily interacting with ecological niches and social environments. That is true not only for low-level skills, but even for high-level domains of categorization, language, and abstract thinking. Embodied cognitive science, AI, and robotics try to build the embodied mind in an artificial evolution. From a philosophical point of view, it is amazing that the new ideas of embodied mind and robotics have deep roots in 20th-century philosophy.

1. Introduction

Modern cognitive science cannot be understood without recent developments in computer science, artificial intelligence (AI), robotics, neuroscience, biology, linguistics, and psychology. Classic analytic philosophy as well as traditional AI assumed that all kinds of knowledge must explicitly be represented by formal or programming languages. This assumption is in contradiction to recent insights into the biology of evolution and developmental psychology of the human organism. Most of our knowledge is implicit and unconscious. It is not formally represented, but embodied knowledge which is learnt by doing and understood by bodily interacting with ecological niches and social environments. That is true not only for low-level skills, but even for high-level domains of categorization, language, and abstract thinking. Embodied cognitive science, AI, and robotics try to build the embodied mind in an artificial evolution. Neuromorphic engineering is, of course, a dramatic challenge of ethics. From a philosophical point of view, it is amazing that traditional concepts of cognitive science and AI with formal representations of knowledge are in a traditional line of philosophers from Descartes, Leibniz, Kant, and Husserl, up to Carnap and Quine, while the idea of an embodied mind has roots in the philosophy of Heidegger, Merleau-Ponty, and Dewey.

2. Classical Interpretations of Cognition: Artificial Intelligence and Philosophy of Mind

In the beginning of classical cognitive science, there was René Descartes' dualism of mind and brain, mind and the external material world. According to Descartes, the human body with the brain is a material machine. It is directed by innate ideas (ideae innatae) which are stored by the human mind in the brain in a clear and distinct manner (clare et distincte). Human mind (res cogitans) is separated from the external world (res extensa) in a strict epistemic dualism. Recognition is made possible by an isomorphic correspondence between internal representations of ideas and external situations and events. Later on, David Hume criticizes that there is neither a causal mechanism in nature nor a causal law in our mind, but only an unconscious reflex of associating sense-impressions (e.g., flashes of lightning and thunder). There are no sharp and definite concepts founded on perceptions, but only more or less fuzzy patterns allowing more or less probable assertions about random events.

In Immanuel Kant's epistemology, recognition is an active process, constructing internal representations of the world by a priori categories. Thus, causal connections of events are actually realized by the category of causality in our mind. Concepts are regulated by formal schemes (»Schema«). Intuition is made possible by spatial and temporal ordering of events. Although based on sensory data, the external world is a subjective construction of pure reason. That is the main message of Kant's transcendental constructivism for modern cognitive science.

A further important step of cognitive philosophy was Edmund Husserl's phenomenology of consciousness. Husserl is in the tradition of Cartesian cognitivism, but emphasizes representational intentionality: in order to perceive, act, and relate to objects, there must be some internal representation that enable us to direct our mind toward each object. In classical artificial intelligence (AI), Husserl's intentional content of consciousness corresponds to the formal representation of a computer program.

How are formal representations of a computer program made possible? From a logical and mathematical point of view, Alan Turing defines a computer independent of all technical and physical details: a Turing machine is a formal procedure, consisting of: a) a control box in which a finite program is placed, b) a potentional infinite tape, divided lengthwise into squares, c) a device for scanning, or printing on one square of the tape at a time, and for moving along the tape or stopping, all under the command of the control box. Every computable procedure (algorithm) can be realized by a Turing machine (Church's thesis). Every Turing program can be simulated by a universal Turing machine. Technically, a universal Turing machine is more or less a general purpose computer.

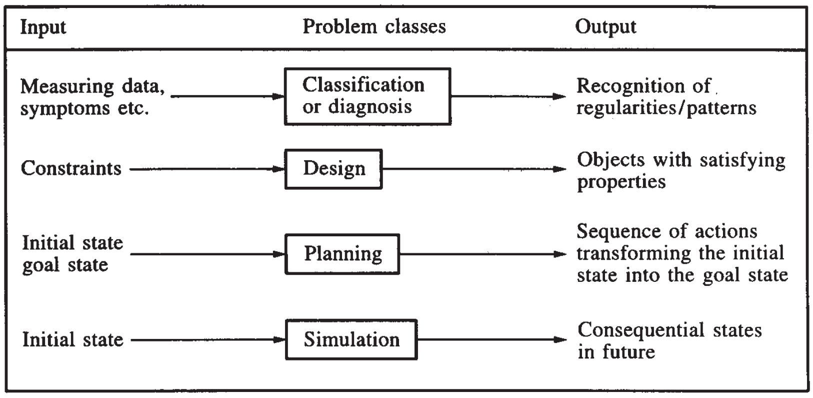
On the background of Turing's theory of computability, we get his computational cognitivism which assumes computational functionalism. According to computational functionalism, the brain as biological wetware corresponds to the physical hardware of a computer. The mind with concepts and logical inferences is understood as the software of a computer (Turing) program with data structures and algorithms. Then, Turing argues as following: if human mind is computable, it can be represented by a Turing program (Church's thesis) which can be computed by a universal Turing machine, i.e. technically by a general purpose computer. Turing and classical artificial intelligence (AI) believed that the human mind is computable in the sense of computational functionalism. Thus, it follows that it is computable by a general purpose computer with sufficient computational power.

Even if people do not believe in Turing's strong AI-thesis, they often claim classical computational cognitivism in the following sense: computational processes operate on symbolic representations referring to situations in the outside world. Further on, these formal representations should obey Tarski's correspondence theory of truth: imagine a real world situation X_1 (e.g., some boxes on a table) which is encoded by a symbolic representation A_1= encode(X_1) (e.g., a description of the boxes on the table). If the symbolic representation A_1 is decoded, then we get the real world situation X_1 as its meaning, i.e. decode(A_1) = X_1. A real-world operation T (e.g., a manipulation of the boxes on the table by hand) should produce the same real-world result A_2, whether performed in the real world or on the symbolic representation:

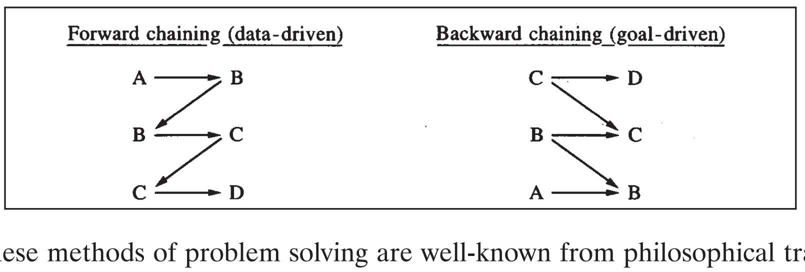
$$\text{decode}(\text{encode}(T)(\text{encode}(X_1)))=T(X_1)=X_2.$$

Thus, there is an isomorphism between the outside situation and its formal representation in Cartesian tradition.

Computational cognitivism assumes that problem solving strategies can be represented by formal rules. A simple rule of traffic demands: IF traffic light is red, THEN traffic stops. We can encode the rule with formal representations A (»traffic light is red«) and B (»traffic stops«) by a so-called production rule A→B. Another example is a problem of diagnosis in medicine: IF patient *x* has a heart attack, THEN *x* has heart encymes in the blood. In general, we can distinguish problem classes of classification, diagnosis, design, planning, and simulation which can be represented by formal IF-THEN or production rules A→B:



Rules can be combined by forward chaining (starting with data A and deducing goal D) or backward chaining (starting with goal D and seeking sufficient premises):



These methods of problem solving are well-known from philosophical tradition, e.g., Pappos' methods of synthesis and analysis, their origin in Aristotelian logic and their development in the philosophy of modern times. There are also many methods of inductive logic and probabilistic reasoning, strategies of proofs and refutations which were implemented into knowledge-based expert systems, but which are also well-known from analytical philosophy (e.g., Carnap, Quine) and philosophy of science (e.g., Popper, Lakatos).

As Clark Glymour emphasized it (Fetzer 1988, 195): Artificial Intelligence is philosophical explication turned into computer programs. Historically, what we think of as Artificial Intelligence arose by taking the explications provided by philosophers and logicians, and finding computable extensions and applications of them. Developments in programming technology have tended to make the process of transforming certain sorts of philosophical explications into programs nearly automatic. Production rule systems exploit the ambiguity between conditional sentences and procedural rules, and permit one to turn theories consisting of a collection of conditionals into a simple program. Most of the philosophical theories used in Artifical Intelligence are not taken from the philosophical literature directly, but that does not make them any the less philosophical. Computer science teaches us that there is more to philosophy than we might have thought: Artificial Intelligence is philosophy.

Knowledge-based expert systems try to represent problem solving strategies for appropriate problem classes. Contrary to conventional programs, expert systems choose appropriate rules automatically by an inference system with forward and backward chaining. Knowledge is the key factor in the performance of an expert system simulating problem solving of a human expert like, e.g., a scientist or a physician in a special domain. The knowledge is of two types. The first type is the facts of a domain that are written in textbooks and journals in the field. Equally important to the practice of a field is the second type of knowledge, called heuristic knowledge, which is the knowledge of good practice and judgement in a field. It is experimental knowledge, the art of good guessing that a human expert acquires over years of work. The heuristic knowledge is hardest to get at because experts rarely have the self-awareness to recognize what it is. Therefore knowledge engineers with interdisciplinary training have to acquire the expert's rules, to represent them in programming language, and to put them into a working program. This component of an expert system is called knowledge acquisition.

But there still is a more fundamental problem with expert systems. They are restricted to a specialized knowledge base without all the background knowledge of a human expert. Human experts do not rely on explicit (declarative) rule-based representations, but on intuition and implicit (procedural) knowledge. A simple example of everyday life is car driving. The first lessons of car driving can still be represented by rules and chaining of rules in textbooks. But no situation in real traffic is completely identical to the premises of a texbook rule. Further on, for using the technical equipment, we need some feeling and sensitivity. How to become a good expert of car driving? As we all know that is only possible by training, practice, and experience. Further on, the background problem is a philosophical challenge as Hubert Dreyfus emphasized (Dreyfus 1979): How should the specialized knowledge base of an expert system be combined with the generalized and structuralized background knowledge of the world which influences the decisions and actions of a human expert? In medicine, when deciding on surgery, a good physician will also take into consideration on objective impressions he has concerning the patient's living conditions (family, job, etc.) and his or her attitude towards life. In expert systems of law, the same aspect could be shown. Despite of all consistent systems of norms, a judge will in the end find a formal scope for possible decisions where he will orient towards his personal outlook on life and the world. Actually, lawyers use hermeneutic methods to interpret the text of laws, in order to find decisions according to the formal law and the material aspects of attitudes and intentions.

With increasing complexity of situations, rule-based representations decay into a diversity of many rules and the user looses any survey. Thus, Marvin Minsky tried to improve knowledge representation by the introduction of frames. They are formal representations of objects and situations, consisting of formal variables for features (called slots) and concrete values (called fillers):

Object	Feature	Value
Zebra	is a	mammal
	colour	striped
	has	hoofs
	size	1.2 – 1.8 m
	living space	Africa

Philosophically, frames are considered as cognitive schemes of categories, organizing our knowledge of objects and situations with internal representations. As we mentioned above, they play a fundamental role in Kant's epistemology. Obviously, they can also be replaced by logical rules: e.g., IF x is zebra, THEN x is striped; IF x is zebra, THEN x has hoofs; etc. But frames collect and arrange a connected concept in the intuitive manner of a graphic scheme instead an endless list of disconnected rules. Scripts are formal representations of time-depending processes with preconditions, objects (Props), and result. Scenes represent static situations and events. A sequence of scenes represent a causal chain of events. An example of everyday life is Roger Schank's restaurant script with typical scenes in an American restaurant:

Restaurant script		
Roles		customer (c), waiter (w), chef (c), owner (o)
Props		tables, chairs, menus, food, bills, money, tip
Preconditions		c has money, c is hungry
Results		c has less money, o has more money, c is less hungry
Scene 1	ENTER	c enters the restaurant
Scene 2	SEATING	c is waiting to be seated, c gets a table, c sits down
Scene 3	ORDERING	c asks w for menu, c studies menu, c orders the meal from w
Scene 4	EATING	w brings the food, c eats the food
Scene 5	PAYING	c asks w for check, c pays check, c leaves tip
Scene 6	LEAVING	c leaves restaurant

After these examples of representations, the question arises if understanding in general can be reduced to formal rules. John Searle explained the problem by his famous thought experiment of the »Chinese room«: using only syntactical rules of symbols, he or a computer is producing answers to Chinese questions written on cards that are handed through a window into the room. Even though he or the computer does not understand Chinese, he or the computer can produce meaningful Chinese sentences by formal rules of Chinese signs. Of course, Searle's thought experiment is an exaggeration, because even for using formal rules we need procedural knowledge. But, we all know that a foreign language is not learnt by studying formal grammar and symbols, but mainly by talking and communicating, i.e. through learning by doing and extending implicit (procedural) knowledge of a language. In short: the rule-based representation of linguistic competence is limited.

As already Wittgenstein knew, our understanding of language depends on situations. The situatedness of representations is a severe problem of applied robotics. A classical robot needs a complete symbolic representation of a situation which must be updated if the robot's position is changed. For example: a robot surronds a table with a ball and a cup on it. A formal representation in a computer language may be ON(TABLE, BALL), ON(TABLE, CUP), BEHIND(CUP, BALL), etc. Depending on the robot's position relative to the arrangement, the cup is sometimes behind the ball or not. So, the formal representation BEHIND(CUP, BALL) must always be updated in changing positions. How can the robot prevent incomplete knowledge? How can it distinguish between reality and its relative perspective? Situated agents like human beings need no representations and updating. They look, talk, and interact bodily, e.g., by pointing to things. Even rational acting in sudden situations does not depend on internal representations and logical inferences, but on bodily interactions with a situation (e.g., looking, feeling, reacting). Imagine a boy on a bicycle who turns suddenly aside in order to avoid a little snail on the road. On the other hand, rational thoughts with internal representations do not guarantee rational acting: a professor of logic may fail in many practical situations, because complex real situations deviate from more or less simplified formal representations.

Thus, we distinguish formal and embodied acting in games with more or less similarity to real life: chess, for example, is a formal game with complete representations, precisely defined states, board positions, and formal operations. Soccer is a nonformal game with skills depending on bodily interactions, without complete representations of situations and operations which are never exactly identical – as our life, only much more simple. According to Maurice Merleau-Ponty, intentional human skills do not need any internal representation, but they are trained, learnt, and embodied in an optimal »gestalt« which cannot be repeated. An athlete like a pole-vaulter cannot repeat her successful jump like a machine generating the same product. As Merleau-Ponty puts it:

> »To move one's body is to aim at things through it; it is to allow oneself to respond to their call, which is made upon it independently of any representation.« (Merleau-Ponty 1962, 139)

Husserl's representational intentionality is replaced by body-based intentionality.

3. Artificial Evolution and Embodied Cognition

Body-based intentionality is wonderful when a healthy organism is acting without conscious control, but it is no mystery. Modern biology and neural sciences give a lot of insights into its origin during the evolution of life. The key-concept is self-organization. In a pre-biotic evolution, self-assembling molecular systems become capable of self-replication, metabolism, and mutation in a given set of planetary conditions. The molecular information of these features is stored in molecular components. It is still a challenge of biochemistry to find the molecular programs of generating life from »dead« matter. Darwin's evolutionary tree of species on earth can be explained by genetic programming of DNA-codes. Mutations are random changes of the DNA-codes, generating bifurcations of the evolutionary tree. Selections are the driving forces. The evolution of nervous systems and brains is embedded in the evolutionary tree of species as a new kind of information processing. A DNA-code is a fixed program which largely does not change during life-time of an organism. Only its population can learn and change the behavior by selection of protypes with changed DNA-codes which are better adapted to certain ecological niches in following generations.

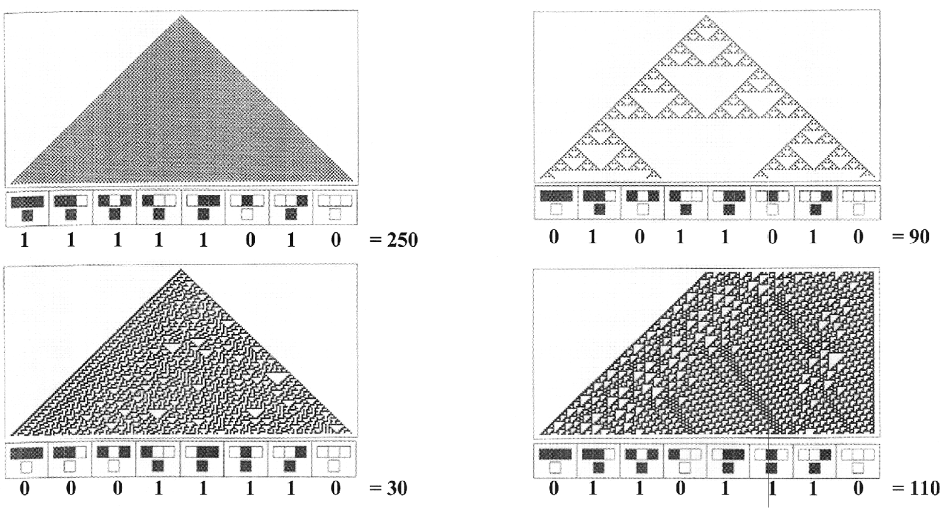
Brains are neural systems which allow quick adaption to changing situations during the life-time of an organism. In short: they can learn. The human brain is a complex system of neurons self-organizing in macroscopic patterns by neurochemical interactions. Perceptions, emotions, thoughts, and consciousness correspond to these neural patterns. The self-organization of cognition is illustrated by the binding problem of visual perception. How is it possible for our visual system to recognize a bound *gestalt* (shape) and not only a set of coloured pixels? In a self-organizing learning process, the brain responds for different *stimuli* with different clusters of synchronously firing neurons. These cell assemblies code the binding of single features in a perceptual object by synchronous neural activities. Their learning rules were discovered by Donald O. Hebb, and recently confirmed by Wolf Singer et alt. In an elder theory Barlow assumed that each feature of an object must be represented by specialized neurons. In order to connect them in a bound shape, he introduced so-called mother-cells. For more complex representations he needs an exploding number of neurons (»grandmother cells«) representing hierarchies of bound features, bound sets of features, bound sets of sets of features, etc. which are empirically refuted by the observation of brain activities.

In the central nervous system, billions of neural cells organize the complex signal and communication process of the human body. Firing and non-firing neurons produce a dense flow of binary signals which are decoded by the brain. After DNA-codes and learning brains, the next step of cellular information processing is done by learning populations. In sociobiology, populations of simple insects like ants organize complex transport, signal, and communication systems by swarm intelligence. There is no central supervisor. The order of the system is self-organizing according to chemical signals between thousands of animals. Populations with swarm intelligence are sometimes called superorganisms or even superbrains. Actually, populations, species, and societies are not only collections of isolated brains, organisms, or people, but they are new kinds of self-organizing systems.

All these steps of natural evolution have more or less become blue-prints for computing and information systems in an artificial co-evolution of technology. I remind the reader of quantum physics with elementary particles and atoms which today deliver the standards for quantum computing, nanotechnology for molecular computing, genetechnology for DNA-computing, biology of evolution for evolutionary algorithms in biocomputing, brain research for neurocomputing of neural nets, cognitive science for soft computing with fuzzy logic, learning algorithms, and affective computing, and, last but not least, sociobiology and sociology for socionics with distributed Artificial Intelligence and multi-agents systems. Let us have a look on some of these steps of artificial evolution.

From a philosophical point of view, Gottfried Wilhelm Leibniz already proclaimed in the end of the 17th century that life can be considered as complex automata: »Every organic body of a living being«, he said in his *Monadology* (§ 6), »is a kind of divine machine or natural automaton surpassing all artificial automata infinitely«. Today, his view is discussed as principle of computational equivalence demanding that for every natural system there is a corresponding computational system. Leibniz' metaphysical idea of automata was made precise by John von Neumann's cellular automata in the end of the 50^{ies} of the last century. Cellular automata are complex systems of finite automata which can be illustrated by cells on a grid with states indicated by numbers or colours. In the binary case, there are only two states 0 and 1, or white and black. The cells change their states in dependence of neighboring cells according to simple local rules. Again, there is no central processor, but self-organization. Special cellular automata can reproduce themselves in sequential generations like living organisms. Every computer can be simulated by an appropriate cellular automaton (CA) and vice versa. There are universal CAs which can simulate any special CA like a universal Turing machine.

The main message of CAs is the following: with simple rules understandable by any pupil, cellular automata can generate all kinds of complex structures in nature. For example, we consider 1-dimensional automata with two states, developing line by line from an initial state at the top of a grid. Each application of a rule depends on the states of three preceding cells. Thus, each automaton is characterized by $2^3=8$ rules. Their eight binary outputs can be decoded by the corresponding decimal number as »DNA-code« of an artificial organism. They can generate completely regular and symmetric patterns like crystals, but also completely irregular and random patterns without any structure (left below) like snow-flakes in a storm or locally correlated complex patterns (right below) like organic structures in nature:



Different increasing complex and random patterns can be generated by the same simple rules of cellular automata with different initial conditions. In many cases, there is no finite program, in order to forecast the development of random patterns. In this case, the process of development is incompressible because of computational irreducibility. If we want to know the future, we must wait and observe the actual development. These insights of cellular automata have enormous consequences in science and philosophy. In the past, scientists believed that the knowledge of laws enable us to compute a dynamical system. Cellular automata show us: even if we know all interacting rules of elementary particles and atoms in physics, of molecules in chemistry, of cells in biology, and of neurons in brain research, we are not necessarily able to compute the dynamics of their complex systems. According to the principle of computational correspondence, complex atomic, molecular, or cellular systems are computational, but they are not necessarily computable.

In the next step of artificial evolution, we consider neural nets working like brains with appropriate topologies and learning algorithms. Neural networks are complex systems of technical neurons, active (»firing«) and nonactive (»non-firing«) in dependence of certain thresholds like biological neurons. The neurochemical interactions between biological neurons are simulated my numerical weights indicating the degree of connections. Again, there is no central processor, no »mother cell«, no thinking or feeling cell, but self-organizing information flow in cell-assemblies according to rules of synaptic interactions (e.g., Hebb's rules or backpropagation). Neural networks try to simulate the synaptic plasticity of living brains with their tolerance to failures and self-adaption to changing situations. Learning algorithms might be supervised like learning with a teacher. In this case, they improve their results by comparing them to certain prototypes (e.g., recognition of stored patterns). They can also be non-supervised, finding new patterns, clusters or concepts by trial-and-error and evolutionary procedures of selection.

Embodiment of neural networks is the aim of embodied robotics: a simple robot with a motor equipment (e.g., wheels) and diverse sensors indicating proximity of objects, sources of light, and collision with obstacles can generate complex behavior by self-organizing neural networks. For example, an embodied neural network has layers of neurons for motor actions (e.g., turning aside, moving forward), and for sensors of proximity and collision. In the case of a collision, the connections between the active neurons of the proximity layer and the collision layer are reinforced by Hebbean learning: a behavioral pattern emerges, in order to avoid collisions in future. That is an example of pre-rational intelligence.

In nature, complex patterns of movements are also not computed and controlled by a central processor, but by self-organizing learning algorithms of neural networks. An example is a grasshopper with six legs which was recently simulated by a little robot of the Technical University at Munich. For each leg there are three modules of moving like lifting, swinging, and coordinating the lifting and swinging parts. Motor knowledge is learnt in an unknown environment and stored implicitly by the distribution of synaptic weights in the nets. During evolution, decentralized modules had a great advantage, because they could be used as building blocks for different organisms in future developments. In the human organism, walking is a complex bodily self-organization, largely without central control of brain and consciousness: motor intelligence emerges without internal representations. A simple robot of the University at Illinois walks down a shallow slope very natural and human-like, only driven by system-environment interaction of gravity, inertia, and collision, rather than by an internal central controller. It is a complex dynamical system, driven into the equilibrium of a limit cycle with steady periodic motion.

Not only »low level« motor intelligence, but also »high level« cognition (e.g., categorization) emerge from complex bodily interaction with an environment by sensory-motor coordination without internal representation. We call it »embodied cognition«: an infant learns to categorize objects and to build up concepts by touching, grasping, manipulating, feeling, tasting, hearing, and looking at things, and not by explicit representations. The categories are fuzzy and may be improved and changed during life (in the sense of Hume). But infants have an innate disposition to construct and apply conceptual schemes and tools (in the sense of Kant). The emergence of embodied cognition was already emphasized by John Dewey:

> »We begin not with a sensory stimulus, but with a sensorimotor coordination… In a certain sense it is the movement which is primary, and the sensation which is secondary, the movement of the body, head, and eye muscles determining of what is experienced.« (Dewey 1896/1981, 127)

Embodied cognition is also the aim of embodied robotics. Consider the following example (Pfeifer/Scheier 2001, 428): A robot with visual, haptic, and motor systems (e.g., camera, gripper, wheels) has the task to collect certain objects and to bring them to a home base. Therefore, it must categorize conductive and non-conductive objects with strongly or slightly textured surfaces. Sensory networks receive inputs from the sensors. These sensory networks are connected to attention and feature maps of corresponding networks which together with the effectors form an attentional sensory-motor loop, modulated by a value map, according to the robot's task. Values represent the intentions and motivations of the robot.

Neural networks can even simulate high level cognitive abilities like talking. A network like NETtalk learns talking like a child by reading more and more unknown texts and improving their pronounciation by comparing it with the trained example of a well-known text (supervised learning with backpropagation). The pronounciation is not represented by rules, but distributed in the synaptic weights of firing cell assemblies with similarity to corresponding brain activities. Networks are successful in pattern recognition. Their synaptic plasticity allows to recognize examples of trained prototypes even if they are fuzzy and noisy in a certain interval of tolerance like human brains. Pattern recognition is applied in emotional computing. A Japanese robot with the name Mark II recognizes emotional expressions of a human face (e.g., happiness, anger, aggression, surprise) with pattern recognition of a neural network and reacts by generating an appropriate facial expression in proper time. This is an example of non-verbal communication.

In chip technology, analog and digital networks are integrated in cellular neural networks like in human nervous systems. Cellular neural networks (CNNs) combine the architecture of cellular automata (CA) with the learning abilities of neural networks. Thus, they can generate all kinds of complex patterns like CAs (pattern formation), but they can also recognize patterns like neural networks (pattern recognition). CNNs are applied as high-speed chips in visual computing and robotics. In pattern recognition, the binding problem arises for living brains as well as for artificial networks: CNNs recognize globally connected patterns and distinguishes disconnected parts. In the so-called »gestalt-psychology« of the last century, people doubted whether it would ever be possible to simulate the recognition of an »holistic« *gestalt* (shape) by »mechanical« procedures. CNNs made it. Another problem of »gestalt-psychology« is the well-known visual illusion of two symmetric faces or a vase. The »gestalt-psychologists« argued that the sudden switching between the two holistic shapes, either two symmetric faces or a vase, can never be realized by mechanical procedures. In human recognition, a preference for one of the two possibilities depends on an initial attention at a random detail, either in the foreground or the background of the picture. In the same manner, a CNN-chip simulates pattern recognition of the face-vase illusion, depending on the evaluation of some pixels in the foreground or background. As CNNs work with massive parallel computing power and universal computation like universal cellular automata, they can also be applied in neurobionics and high tech medicine: brain electrical activity (e.g., EEG-signals) is recorded from electrodes in order to detect the patterns of an impending disease (e.g., epilepsy) and to enforce suitable medical preventions (e.g., drug infusion).

In our philosophical context, neural computers make a thought experiment more realistic which was introduced by Hilary Putnam two centuries ago as a horror picture show (Putnam 1981, 21): suppose to be an isolated Cartesian brain removed from its body and living in a nutrient fluid of a vat. The afferent nerve endings are connected with a super neural computer (e.g., a CNN-chip) producing all sensory inputs of the brain. Can the brain alone decide the statement »I am a brain in a vat«? The disembodied brain cannot: concepts like »brain«, »vat«, etc. do not refer to real things, but to internal representations of a virtual reality produced by a neural computer. Even self-experience of the own brain in the sense of Descartes' »Cogito« needs a body and bodily interactions: »Sum, ergo cogito.«

In a recent movie, Steven Spielberg illustrates the possibility that all our thoughts are determined and computable. In his *Minority Report*, a special agency of police is able to forecast future thoughts of people in order to prevent future crimes. The lost of free will would have enormous consequences for our laws and societies. Actually, people could not be responsible for their decisions and actions. Their behavior would be determined by genetic and neural dispositions. Crime would be a problem of medicine and software engineering. Lawyers and teachers should be replaced by physicians, genetic and neural engineers. Obviously, thoughts and emotions correspond to complex patterns of neural cell-assemblies generated by simple synaptic rules of neural interactions (e.g., Hebbean learning rules). Thus, brain reserchers assume that brain processes are determined and computable, because their laws of neural interactivity are well-known. They argue on the background of school-physics: the future trajectory of a planet is computable, because we know Kepler's deterministic law. But, even in the case of a planetary system, we must take into account the many-bodies-problem of several interacting planets with the sun, generating instability and even chaos which prevents forecasts in the long run, although the physical laws are deterministic and well-known. Pattern formation of cellar automata demonstrates that the global behavior of all cellular interactions may be too complex in order to be forecast in all details by a finite program, although the local rules of interacting cells are very simple and well-known.

The human brain has a many-bodies-problem of 10^{11} neurons with 10^{14} synaptic interactions. Thus, according to the principle of computational correspondance, the brain is a computational system, but not computable. Actually, the steady local interactions of neurons produce global random noise with islands of structured patterns (attractors) representing our thoughts, perceptions, feelings, consciousness, and motor activities. Therefore, the brain has stochastic dynamics, and therefore, at best, we can only detect some structured patterns and compute some future trends in a short run like clouds and their future development in wheather forecasting. Stochastic dynamics make free will at least possible.

4. Global Networking and Embodied Cognition

A species, population, or society is not only the sum of its individual brains and bodies, but a new kind of superorganism or superbrain generated by the interactions of its communicating and interacting individuals. After the transport, information, and communication systems of natural evolution (which were discussed in the second chapter), global communication networks (e.g., the World Wide Web) are emerging in a technical co-evolution with surprising similarity to self-organizing neural networks of the human brain. Like neural impulses in a nervous system, data traffic is the information flow in the internet, constructed by data packets with source and destination addresses. The routers are nodes of the net determining the local path of each packet by using local routing tables with cost metrics for neighboring routers. A router forward each packet to a neighboring router with lowest costs of destination. The buffering, sending, and resending activities of routers can cause congestion and chaos. We can observe complex patterns of high, medium, and low density of data traffic with similarity to patterns of neural activities in a brain.

Computational and information networks have become technical superorganisms evolving in a quasi-evolutionary process. Computer networks are computational ecologies. As the Internet is a highly complex information network, we have to manage information flow with loss of information in chaotic situations. »Lost in the net« is a popular slogan of these problems with increasing complexity. The information flood in a more or less chaotic Internet is a challenge for intelligent information retrieval. According to the synaptic plasticity of a brain, information retrieval should be optimized by soft computing: Information Retrieval (IR) in the Internet requires deciding procedures in order to evaluate and select the most relevant documents according to certain constraints. In binary (Boolean) logic, a document is either relevant (1) or not (0) for an information query. Actually, a document is more or less appropriate to our interests. Soft constraints are typical for human decisions and information processing. In fuzzy logic, it has a degree of relevance in the internal [0,1], depending on a user's profile and changing preferences.

Further applications of soft computing are genetic algorithms, in order to improve information retrieval. In natural evolution, genetic algorithms optimize populations of chromosomes in sequential generations by reproduction, mutation, and selection. In information retrieval, they are applied for optimizing queries of documents. A chromosome is a sequence of documents which are characterized by weighted key terms in binary codes. Populations are sets of chromosomes. Mutation means random change of binary digits. Sequential binary codes can be recombined. Fitness degrees measure the relevance of documents. Selection is the evaluation of populations of documents.

It is not only a metaphor to consider the Internet as a kind of superbrain with self-organizing features of learning and adapting. We could use the analogies with a brain as heuristic devices to manage the information flood in the Internet. Information retrieval is already realized by neural networks adapting to the information preferences of human users with synaptic plasticity. Many-layered neuronal nets can be applied for optimizing queries of documents. Synaptic connections (»weights«) between neurons change according to learning algorithms. The relevance of terms in a document corresponds to weights between the neurons of terms and documents. Neurons fire, if the sum of weighted inputs surpasses a critical threshold. A learning algorithm delivers a first query result by propagation. Deviations of user's preferences are weighted and propagated back to the term and input layer (»backpropagation«) and are improved during several iterations.

In sociobiology, we can learn from populations of ants and termites how to organize traffic and information processing by swarm intelligence. From a technical point of view, we need intelligent programs distributed in the nets. There are already more or less intelligent virtual organisms (agents), learning, self-organizing and adapting to our individual preferences of information, to select our e-mails, to prepare economic transactions or to defend the attacks of hostile computer viruses, like the immune system of our body. Virtual agents are designed with different degrees of autonomy, mobility, reactivity or learning capabilities for communicating. They communicate and cooperate with their virtual environment as local sphere of influence.

There are stationary agents doing their duties localized in special servers or mobile agents which can be sent as byte codes into the World Wide Web, doing their services without online connection of client and server. E-commerce is a challenge for complexity research which only can be managed by the help of virtual agents, supporting economic transactions. In future, genetic algorithms will enable us to breed populations of agents in a complex evolution of virtual life. Populations of agents can reproduce themselves by genetic algorithms in order to optimize their information retrieval according to the queries of a user. Agents start with a user's profile. They weight the relevance of a document, e.g., by determining the distance (number of links) between key words of the document and the key words of the query. The »energy of life« of an agent increases or decreases according to the success or failure of its query. Successful agents are selected, mutate their genotype and reproduce themselves.

Agents communicate with speech-act types of the computer language KQML (Knowledge Query and Manipulation Language). Speech-acts are designed as intentions, according to John L. Austin's and John Searle's philosophy of language:

Speech-Act Type/ Performative	Meaning
achieve	S wants that R makes a proposition true in his environment
advertise	S is especially qualified for realizing a speech-act type
ask-all	S wants to receive all answers of R‘s knowledge base
ask-one	S wants to receive one answer of R‘s knowledge base
broker-one	S wants that R finds help to answer a speech-act
deny	The speech-act is no longer true for S
delete	S wants that R deletes some facts from his knowledge base
recommend-one	S wants to get the name of an agent who can answer a speech-act
recruit-one	S wants that R recruits an agent to realize a speech-act
sorry	S has not the necessary knowledge or information
subscribe	S wants continuous information of R‘s answers to a speech-act
tell	S sends information

Like human beings, artificial agents can express their intentions by language and initiate a reaction of its communication partner. This is another prominent application of a philosophical concept in computer science.

In affective computing, agents are equipped with a software simulating features of emotional intelligence. Connectionistic models combine complex emotions from basic types like, e.g., fear, anger, or joy. Their intensity at a certain time depends on excitatory and inhibitory influences of other emotion types and elicitors of neural, sensorimotor, motivational, and cognitive kind. The question arises why agents should be equipped with at least fragments of emotions. The reason is that in fuzzy situations of incomplete information people quickly trust more in their emotions and intuitive experiences than in time-spending analytical reasoning. Obviously, connectionistic models are only behavioral. But, in principle, they could be embodied into neurochemical brains and bodies in order to produce feelings.

Human beings are no virtual agents. We are embodied beings embedded in physical environments, ecological and social niches. We like to move and interact bodily. Our brain is largely influenced by our body. The disembodied brain is a Cartesian illusion. Thus, computer power should not be concentrated in some few supercomputers in order to generate a virtual reality as counter world to our physical world. We like to act in our natural world with familiar things of everyday-life, but supported by the advantages of computational functions. In short: computational power should be distributed in the things of daily use. Therefore, things should not be virtualized in virtual reality, but virtuality should be embodied in things of human life. That is the philosophy of ubiquitous computing.

In our beginning century, global networking does not only mean increasing numbers of PC’s, workstations, servers, and supercomputers interacting via data traffic in the Internet. Below the complexity of a PC, cheap and smart devices of low-power are distributed in intelligent environments of our everyday world. Examples are tabs, pads, and boards: inch-scale machines that approximate active Post-It notes, foot-scale ones that behave something like a sheet of paper, a book or a magazine, and yard-scale displays that are the equivalent of a blackboard or bulletin board. Tabs, pads, and boards are just the beginning of ubiquitous computing. Smart devices are intelligent microprocessors embedded in an alarm clock, the microwave oven, the TV remote controls, the stereo and TV systems, the kids’ toys, etc. Ubiquitous computing makes »things that think«, not only highly intelligent supercomputers, but an intelligent superorganism with swarm intelligence. The third generation (3G) services of wireless communication include packet networks and interconnectivity of computerized appliances, such as phones, faxes, printers, software radio, etc. The enabling technologies demand for faster data converters, more powerful processors, Java and other forms of downloadable software. The technical development of 3G-communicators is an interdisciplinary task of system engineering.

Like GPS (Global Position System) in car traffic, things of everyday life could interact telematically by more or less intelligent sensors. A car driver using GPS is telematically guided by a network of neighbor GPS stations. In future, the processors, chips, and displays of these smart devices do not need a user's interface like a mouse, windows, or keyboards, only just a pleasant and effective place to get things done. Wireless computing devices of all scales become more and more invisible to the user. Ubiquitous computing enables people to live, work, use, and enjoy things without being aware of their computing devices.

From a technical point of view, ubiquitous computing is a challenge of global networking by wireless media access, wide-bandwidth range, real-time capabilities for multimedia over standard networks, and data packet routing. Not only millions of PC'c, but billions of smart devices are interacting via the Internet. They are real physical things of different scale, but with virtual data shadows in the Internet requiring a powerful complexity management of data traffic. The overwhelming flow of data and information enforces us to operate at the edge of chaos.

In the 21^{st} century, information, communication, and biotechnology are growing together. Therefore, information processing requires learning from nature. Information can be generated, transmitted, stored, processed, and represented in nature by sense organs, the nervous system, brain, cognitive processes like learning and thinking, language, motorics, perception, and communication, which are simulated in technology by physical, chemical, and biological sensors, light-wave conductors, electronic, optical stores, microprocessors, neural nets, robotics, virtual reality, ubiquitous computing, artificial life and intelligence, altogether aiming at learning, adapting, and self-organizing evolutionary complex systems.

We have considered the dynamics of natural systems (e.g., atomic, molecular, genetic, neuronal systems), computational systems (e.g., quantum, molecular, DNA-, bio-, neurocomputing systems), global networking (e.g., internet, routing, information retrieval, multiagent systems), and ubiquitous computing (e.g., mobile phones, GPS, PDA, smart devices, intelligent environments). Global networking is no longer only a challenge of technical development. Ubiquitous computing could improve the human interface with information systems, but it must not perplex people by a diversity of technical equipments. Global networking must be developed as calm and invisible technology. Calm and invisible computing tries to integrate global networking and information processing in human environments and daily life without enslaving people by technical scenarios. Global networking must be developed as a technical service of mankind, no more nor less. Thus, information processing in global networks cannot only be pushed by technical sciences. It must be an interdisciplinary task of microelectronics, computer science, information science, but it is also a challenge of cognitive science, sociology, and humanities.

From an anthropological point of view, ubiquitous computing means distribution of computational functions in the infrastructure of our daily life. The interface of a user with a single computer simulating all kinds of objects, events, and actions in virtual reality is replaced by the familiar infrastructure of real things for daily use which are equipped with hidden computational functions. Interactions are largely wireless. From a philosophical point of view, the classical interface of user and computer corresponds to the dualism of subject and object in Kantian epistemology, or Descartes' and Hussserl's distinction of consciousness and external world. According to Martin Heidegger, the traditional opposition of subject and object must be overcome for common-sense understanding. Our familiarity in situations of daily life does not consist in formal representations of rules and facts, but rather consists of dispositions to respond situations in appropriate ways. Heidegger called the infrastructure »being-in-the-world« which should replace the traditional relation of subject and object, consciousness and external world. Thus, computer technology must be embedded in human »Dasein« in order to support our *being-in-the-world*. Our mind is embodied in the infrastructure of our daily life and not caught in the isolated cave of our brain.

5. Philosophy beyond Cognitivism

What are the philosophical perspectives beyond classical cognitivism of subject and object, consciousness and external world, user and computer? Beyond classical cognitivism means no restriction to mental representations and special kinds of natural intelligence in the sense of some IQ-test, but analyzing all kinds and complex degrees of self-organizing, pre-rational and rational, sensory-motor and emotional cognition which have been developed in evolution. In short: beyond classical cognitivism means embodied cognition. In the same manner, beyond classical Artificial Intelligence means no restriction to formal representations and special kinds of Artificial Intelligence in the sense of a Turing test, but building all kinds and complex degrees of self-organizing computational systems as service systems of human life: thus, beyond classical AI means the new AI of embodied cognition.

Using the laws of complex self-organizing systems does not only mean simulation of existing organisms in nature, but finding new innovations for human purposes. In the history of technology, mankind learnt to fly not by simulating the flight of a bird, but by the innovation of airplanes. They are new solutions of the laws of aerodynamics which were not found by natural evolution. Another example are the laws of neural networks. Brains and nervous systems are only some few solutions which were found by natural evolution. Chip-technology delivers new successful innovations with sometimes differing procedures. We should look for technical solutions of self-organizing systems as service systems of mankind. Thus, we need an interdisciplinary approach of human-centered technology with cooperation of robotics, computer science, AI, cognitive sciences, life sciences, and social sciences.

Obviously, many problems of old and new cognitive science, old and new AI, robotics, brain research, etc. have deep philosophical roots in classical and analytical philosophy. Further on, the conception of embodied mind is rather popular – not only in philosophy: bodiness, health, and wellness are topics of public interest. Health is a top issue of public budgets. Life science has become the leading science in 21st century (after physics in the 20th century). Economists proclaim that the 5th Kondratieff cycle of information society is followed by the 6th Kondratieff cycle of health and life industry. Actually, life, information, and computer science are growing together in evolution theory. From a philosophical point of view, my conceptions of technics and bodiness have an old tradition. In the original (Greek) meaning, technics are purposeful means as human service. Our body is no Cartesian machine or Platonic cave of the soul. In Aristotelian tradition, embodiment means the whole organism with its incorporated entelechy and intentionality. It is our individual source of life, creativity, and wellness. We should take care of it.

References:

Dewey, »J. (1981): The reflex arc in psychology«, in: *Psychological Review* 3 1896, 357–370 (reprinted in J. J. McDermott (ed.), *The Philosophy of John Dewey*, Chicago: University of Chicago Press, 136–148.

Dreyfus, H. L. (1991): *Being-in-the-World: A Commentary on Heidegger's »Being and Time«*, Cambridge MA.: MIT Press.

Dreyfus, H. L. (1979): *What Computer's can't do – The Limits of Artificial Intelligence*, New York: Harper & Row.

Dreyfus, H. L. (1982): *Husserl, Intentionality, and Cognitive Science*, Cambridge MA: MIT Press.

Fetzer J. H. (ed.), (1988): *Aspects of Artificial Intelligence,* Dordrecht: Kluwer Academic Publishers.

Floridi L. (ed.), (2003): *Philosophy of Computing and Information*, Oxford: Blackwell.

Mainzer, K. (2003): *Thinking in Complexity. The Computational Dynamics of Matter, Mind, and Mankind*, 4th enlarged ed., New York: Springer.

Mainzer, K. (2003): *KI – Künstliche Intelligenz. Grundlagen intelligenter Systeme*, Darmstadt: Wissenschaftliche Buchgesellschaft.

Mainzer, K. (2003): *Computerphilosophie – Zur Einführung*, Hamburg: Junius Verlag.

Mainzer, K. (1999): *Computernetze und virtuelle Realität. Leben in der Wissensgesellschaft*, Heidelberg: Springer.

Mainzer, K. (1997): *Gehirn, Computer, Komplexität*, Heidelberg: Springer.

Merleau-Ponty, M. (1962): *Phenomenology of Perception*, Routledge & Kegan Paul.

Pfeifer R./Scheier C. (2001): *Understanding Intelligence*, Cambridge MA: MIT Press.

Putnam, H. (1981): *Reason, Truth, and History*, Cambridge MA: MIT Press.

Schank R. C./Childers, P. G. (1986): *Die Zukunft der Künstlichen Intelligenz. Chancen und Risiken*, Köln.

Searle, J. R. (1969): *Speech Acts*, Cambridge MA: MIT Press.

Klaus Mainzer

Der verkörperte Geist

Über komputationale, evolutionäre und philosophische Interprätationen der Kognition

Die moderne Kognitionswissenschaft kann nicht verstanden werden ohne Einbeziehung der neuesten Errungenschaften aus der Computerwissenschaft, künstlichen Intelligenz (KI), Robotik, Neurowissenschaft, Biologie, Linguistik und Psychologie. Die klassische analytische Philosophie, wie auch die traditionelle KI, setzten voraus, dass alle Arten des Wissens explizit durch formale oder Programmsprachen dargestellt werden müssen. Diese Annahme steht im Widerspruch zu den rezenten Einsichten in die Evolutionsbiologie und Entwicklungspsychologie des menschlichen Organismus. Der grösste Teil unseres Wissens ist implizit und unbewusst. Es ist kein formal repräsentiertes, sondern ein verkörpertes Wissen, das durch Handeln gelernt und durch körperliche Interaktion mit ökologischen Nischen und gesellschaftlichen Umgebungen verstanden wird. Dies gilt nicht nur für niedere Fertigkeiten, sondern auch für höher gestellte Domänen: Kategorisierung, Sprache und abstraktes Denken. Die verkörperte Erkenntniswissenschaft, KI und Robotik versuchen, den verkörperten Geist in einer artifiziellen Evolution zu bilden. Vom philosophischen Standpunkt gesehen ist es erstaunlich, wie tief die neuen Ideen des verkörperten Geistes und der Robotik in der Philosophie des 20. Jahrhunderts verankert sind.

Klaus Mainzer

L'intellect incarné

Sur les interprétations computationnelles, évolutives et philosophiques de la connaissance

La science cognitive moderne ne peut être comprise sans les progrès récents en informatique, intelligence artificielle, robotique, neuroscience, biologie, linguistique et psychologie. La philosophie analytique classique et l'intelligence artificielle traditionnelle présumaient que toutes les sortes de savoir devaient être représentées explicitement par des langages formels ou programmatiques. Cette thèse est en contradiction avec les découvertes récentes en biologie de l'évolution et en psychologie évolutive de l'organisme humain. La majeure partie de notre savoir est implicite et inconsciente. Elle n'est pas représentée formellement, mais constitue un savoir incarné, qui s'acquiert par l'action et se comprend en interaction corporelle avec nos niches écologiques et nos environnements sociaux. Cela n'est pas seulement vrai pour nos aptitudes élémentaires, mais aussi pour nos facultés supérieures de catégorisation, de langage et de pensée abstraite. Science cognitive incarnée, l'intelligence artificielle, ainsi que la robotique, tentent de construire un intellect incarné en évolution artificielle. Du point de vue philosophique, il est admirable de voir à quel point les nouvelles idées d'intellect incarné et de robotique sont ancrées dans la philosophie du XX^e siècle.