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# NEUROBIONICS

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editors

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## An Interdisciplinary Approach to Substitute Impaired Functions of the Human Nervous System

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## PREFACE

This book compiles a selection of reviewed papers of the "1st International Workshop on Neurobionics" held in Goslar (Germany) from February 28th to March 1st, 1992. This meeting assembled scientists from all over the world representing the research fields, which make contributions to the goal of neurobionics: to elaborate methods for the repairment and substitution of impaired functions of the human nervous system.

The 20 contributions in this book are arranged in 6 chapters, which represent the internal structure of the novel interdisciplinary research field "neurobionics".These internal structure consists of theoretical sciences (philosophy, mathematics, neuroinformatics, computational neuroscience), basic biological sciences (molecular biology, cell biology, biological network neuroscience, neurophysiology), technical engineering (microelectronics, micromechanics, robotics, microsystems), and clinical neurosciences (neurodiagnostics, neurology, neurosurgery, neurorehabilitation).

Furthermore, this book includes a discussion, held in Goslar, on organizational problems emerging in the research field "neurobionics". It is hoped that this discussion indicates that a new kind of partnership between the above mentioned, various disciplines is mandatory.

We are grateful to the outstanding scientific minds for their contribution and joined effort in the founding of this new scientific direction. This, using the words of Aristotle, does not happen by chance but for necessity. Hopefully, this publication will set the coordinates for an international and interdisciplinary research field dealing with a subject intrinsic to man´s mind and it´s biological carrier which may be partially replaced by artificial means in the future.

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Hannover, December 1992 — The Editors

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# GENERAL INTRODUCTION

Neurobionics/H.-W. Bothe, M. Samii and R. Eckmiller (Editors)



# NEUROBIONICS - A NOVEL FACULTY BETWEEN ETHICS, NEUROBIOLOGY, COMPUTATIONAL TECHNOLOGIES AND CLINICAL NEUROSCIENCES

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## ABSTRACT

Neurosurgery as a medical discipline, responsible for maintaining the health of the biological carrier (=brain) of the human mind, thus hovers between ethics as a philosophical discipline, basic natural science disciplines, such as computational neuroscience, and the clinical application of this knowledge in the case of the patient suffering from illness.

Therefore, in respect of the well-being of our brain-mind entity, the faculty "Neurobionics" is to be formed which has set itself the following principal aims:

1. development of tools placed at neurosurgery's disposal to substitute failed parts of the human brain by artificial carriers of information-processing
2. international and interdisciplinary cooperation to achieve aim 1
3. the integration of humanities, such as philosophy, in the field of natural sciences and a prior ethical evaluation of prospective projects
4. the orientation of all parts of the faculty towards the medical aim of helping patients with diseases of the central nervous system

"Neurobionics" has to constitute itself from different disciplines. Among them are ethics, epistemology, fractal geometry, molecular biology, molecular electronic devi-

ces, computational neuroscience, neuroinformatics, hardware engineering, software engineering, robotics, behavioural science and neurosurgery. The logical connection of the various branches and their collaboration in respect of the project's aims is conceptualized in the following introduction to "Neurobionics".

## 1. SCIENTIFIC PREMISSES

The idea of establishing "Neurobionics", a faculty in the service of the human brain and mind, based on international and interdisciplinary cooperation, did not evolve by chance but was the logical consequence of the cultural history and scientific development of mankind. By the end of the 20th century, this development has produced a large number of "neurosciences" which have accumulated immense knowledge. On the threshold of the 21st century and with the future in mind, these independent bodies of knowledge need to be brought together in the proposed discipline as in a burning glass for curing the brain-mind phenomenon of our existence.

### 1.1 Brief overview of the history of epistemology

The cultural beginnings of Western European civilisation and technology can be found 2500 years ago in the age of classical Hellenism. At that time, the conceptual distinction between body and mind had already been made. The mind has since then been contrasted to the physical world and is, as a subject, due to its cognitive faculty, able to adapt this world to its own structure, i.e. to objectify it. The method of quantification is, in this regard, the crucial aid for the adaptation of the external world to the perceiving subject.

Philosophy has attempted to find here the cognitive organ of the human mind, for purposes of consistent application to the physical world, by its subdisciplines responsible for this problem: epistemology and, later, scientific theory. In doing so, philosophers were constantly in close dialogue with natural scientists and were indeed themselves often acknowledged authorities in the empirical sciences of their time. A temporary high point in philosophical epistemology was reached with Kant who sought to establish the "conditions of possibility" of what is today classically called physics. He described the cognitive organ used by the human mind (which naturally consists of a number of parts, only one of which is the cognitive faculty) to objectify the material world in a way which is still applied today in the majority of sciences. Discursive, reductionist or even sequential thought is based on the premise that the processes of the world are deterministic and linear and therefore predictable. The reductionist cognitive organ consists of the concepts of "space" and "time", of the logical categories and rules of association and the apparatus of conceptualisation best described by the metamathematical expression of "symbolic representation".

Reductionist thought first reached the bounds of predictability in the early part of the 20th century with the development of the theory of relativity and quantum mechanics. The hitherto fixed relationship between the concepts of "space" and "time" as a means of empirical research vacillated and certain phenomena could only be conceptualised via stochastic, i.e. indeterministic, auxiliary structures.

The aspect of unpredictability has in the meantime come to light in many areas of the empirical sciences: meteorology, cell biology, economics, linguistics, astronomy and neuroinformatics. The part of the world which can be comprehended with the classical cognitive organ seems to be increasingly limited: whole areas appear to be of a non-linear and indeterministic nature.

The phenomenon of no longer being able to study our world with the conventional media of our cognitive apparatus is more apparent than ever at the end of the 20th century and, at the same time, classic in the philosophical sense. For 2500 years, only one part of the discipline of philosophy, the theory of knowledge and science (epistemology), was concerned with the cognitive faculty. Since the middle of this century, however, numerous empirical neurosciences have arisen which have set themselves more or less the same research aim as had previously epistemology. These however come up against the same limits as those mentioned above with regard to the reductionist method: the non-predictability of the information-processing mechanisms of neuronal structures.

As humans, we have no other resource than this cognitive apparatus, as described above, to obtain knowledge about the physical world. However, the neurosciences now open up the possibility of electronically copying naturally occurring neuronal networks, with regard to the structure of their nodes and their connections with each other. The knowledge acquired by the application of reductionist principles to the nerve cells can be applied artificially with the aid of software to neuro-microprocessors. After the manufacture of a hardware simulation and software programming of the nodes forming a network, the function of such networks, once they had been brought into operation, was found to be no longer predictable on the basis of reductionist theory. Nonetheless, for the first time, we have an empirical, experimental model available for the formulation of epistemological questions, with the possibility of studying problems of the following kind: to what extent can our reductionist, deterministic cognitive method affect a non-linear, indeterministic system? If the principles of fractal geometry - iteration, regeneration and self-similarity - are applied to the aforesaid experimental situation of neuronal networks and the classical cognitive faculty, we can hope that additional possibilities for the acquisition of knowledge will be opened to the human mind in the future: the capacity of controlling the non-linear world by linear knowledge about how non-linear phenomena can be influenced by linear phenomena. The experimental production of neuronal networks could thus bring about a scientific change in paradigm as defined by Kuhn (13).

**1.2 Progress of neurosurgery and neuroprosthetics research**

Standing, as it does, at the interface between ethics, natural science and technology, medicine has the role of integrating the results of research by these individual disciplines and making them useable for the well-being of its patients.

Neurosurgery, as a specialist medical area, is concerned with the central nervous system and, in particular, with the brain. This is the biological medium of intellectual capabilities. In the course of his daily work, the neurosurgeon affects, by his medically justified interventions in the brain, the innermost core of human existence, namely the mind. For this reason, he must not only bring to bear the fundamental principles of natural science with regard to the brain but also knowledge about the human mind and its function.

In the past 20 years, neurosurgery has been able to achieve significant progress in the treatment of its patients. The most notable successes in this regard have been achieved by the introduction of diagnostic imaging procedures (computerized and nuclear magnetic resonance tomography) and by the use of microsurgical procedures during operations. Nonetheless, many problems in the treatment of patients with brain diseases are unresolved. For example, the central nervous system of the adult human is only able to replace destroyed areas of tissue to a very limited extent in terms of function. This is due to the inability of a nerve cell to subdivide further after completion of the embryonic phase, as do the cells in the remaining organs of the body. Thus, neuronal cell groups destroyed due to illness or accident often lead to permanent functional disabilities. Today, there are already a few initial attempts of replacing failed functions of the nervous system.

The fate of paraplegic patients is today characterised by a sense of total hopelessness. The spinal cord is, like all parts of the central nervous system, regarded as incapable of regeneration (although even this fact can no longer be regarded as irrefutable in the light of the latest discoveries in molecular biology). For this reason, with patients with a damaged spinal cord and subsequent paraplegia, initial attempts have been made to stimulate the standing and walking functions with the aid of electrodes placed on the skin of the legs. About 8 of these electrodes are arranged on each leg such that they lie over the undamaged peripheral nerves. Electrical impulses from the electrodes, via the stimulation of the appropriate nerves, then effect a contraction of the musculature served by these nerves. Different stimulation frequencies and stimulation current densities induce corresponding muscle contractions. The coordination of the muscle excitations needed to enable patients with damaged spinal cords to stand and even move forward is assumed by a microprocessor, which controls the stimulation given by the surface electrodes as required. The limits of this technology lie in the limited capacity for the attachment of surface electrodes and the sequential microprocessor, which, although primitive for biological information-processing purposes, is the only kind available.

Decisive progress could be achieved in the treatment of paraplegics if the stimulation of different muscle groups could be carried out submicroscopically, directly on the branching of the ends of the peripheral nerves without the use of inorganic metal electrodes. Biotechnical connectivity is thus a challenge to molecular biology, in cooperation with a new discipline, that of molecular electronic devices, which endeavours to produce electronic components from organic molecules. The processors controlling the electrodes and processing the information must undoubtedly be produced on the principle of artificial "neuronal networks" if they are to achieve a data-processing speed in line with the information theory requirements of the human walking and standing apparatus. To produce these microprocessors based on "neuronal networks" requires cooperation between the theoretical disciplines (fractal geometry), highly specialised basic research (computational neuroscience, neuroinformatics) and the most advanced microprocessor production (high-tech hardware engineering).

A further example of the artificial replacement of failed neuronal functions comes in the form of the replacement of the inner ear by the cochlear implant. The peripheral organ of hearing, the cochlea, can fail due to various diseases of the inner ear. If the auditory nerve is intact, a 25-pole electrode can be implanted by microsurgery through the osseous cochlear spiral as a replacement for the organ of Corti. The auditory nerve, originally stimulated by the organ of Corti, is now electrically excited via these electrodes in simulation of the spatial and temporal patterns otherwise produced naturally with certain acoustic phenomena. The task of the collection and processing of acoustic phenomena and the conversion of them into suitable electrode impulses is, here too, assumed by sequential microprocessors programmed on the basis of relevant knowledge in the field of linguistics (phonetics and semantics).

While the perception of sound is possible with a cochlear implant, in terms of quality, it is not comparable with that achieved by an intact hearing organ.

Furthermore, the organ of Corti can only be replaced if the auditory nerve is intact. In contrast to this, many of the clinical cases coming before neurosurgeons have tumours of the auditory nerve, known as acoustic neurinoma. The removal of such tumours harbours the danger of damaging the auditory nerve with subsequent deafness of the patient. If it were possible to connect an artificial network directly in the area of the central auditory pathway, the sense of hearing could be restored despite the loss of the auditory nerve. Here too, molecular biology is called upon to produce the biotechnical connectivity and neuroinformatics to provide the necessary information-processing system.

### 1.3 The need for interdisciplinary cooperation

If we look at the problems encountered in the attempt to restore the functions of failed parts of the central nervous system by artificial substitutes, it becomes apparent that cooperation between molecular biology, neuroinformatics and neurosurgery is an indispensable and fundamental precondition, as is the specialised support of additional theoretical (epistemology, fractal geometry), basic science (biocybernetics, computational neuroscience), medical (neurophysiology, neurorehabilitation) and engineering (hardware engineering, software engineering, robotics) disciplines.

No-one can be ignorant of the fact that over the past 50 years, a technology has developed with capabilities which in some respects simulate human intellectual skills: the electronic microprocessor and its technical application in the computer. In this regard, we intentionally do not use the phrase "artificial intelligence" to avoid the pitfalls of one of the most serious terminological confusions of recent years. On the one hand, it is very difficult to define what intelligence actually is and, on the other, it is still undoubtedly a long way from being technically feasible with the non-biological media currently available. Nonetheless, the functions of human intellectual faculties can be partially simulated with artificial media.

A comparison of the speed of evolution of the biological medium with that of the artificial produces the following picture: during its whole evolutionary period on earth, the biological medium, the brain, has evolved over several million years such that it is today able to process 10 billion ($10^{12}$) bits per second with an internal storage capacity of 10 trillion bits. The development of artificial media really only seriously got under way 50 years ago. In 1940, the Zuse 3 achieved a processing speed of 40 ($\sim 10^1$) bits per second with an internal memory of 20 ($\sim 10^1$) bits. 10 years later the