**Development of Complex Curricula for Molecular Bionics and Infobionics Programs within a consortial* framework****

**Consortium leader**

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**Consortium members**

# SEMMELWEIS UNIVERSITY, DIALOG CAMPUS PUBLISHER

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**Molekuláris bionika és Infobionika Szakok tananyagának komplex fejlesztése konzorciumi keretben

***A projekt az Európai Unió támogatásával, az Európai Szociális Alap társfinanszírozásával valósul meg.

# NEURAL INTERFACES AND PROSTHESES

**(Neurális interfészek és protézisek )**

## LECTURE 1

# INTRODUCTION

**(Bevezetés)**

**GYÖRGY KARMOS**

Investing in your future
New Hungary Development Plan

# AIMS OF THE COURSE:

- In this course the students will become familiar with the new developments of neural engineering in the field of neuroprosthetic devices that can restore lost neural functions. These devices require direct interfaces with the peripheral and central nervous system. Some of these devices are already routinely used in the clinical practice like the cochlear prostheses for restoring hearing, others are still in the developmental or experimental phase.
- The lectures will give summary of the recent results in the divergent fields of neural interfaces and prostheses. Both engineering and medical aspects of the field will be shortly covered in the lectures.

# DEFINITIONS

- **Neuroprosthetics** is a discipline related to neuroscience and biomedical engineering, its main activity is the development and application of neural prostheses.
- **Neural prostheses** are a series of devices that can substitute a motor, sensory or cognitive modality that might have been damaged as a result of an injury or a disease.
- **Neural interface** is a connection between the living tissue and a man-made device, in most case a bioelectrode.
- **Electrode-tissue connection** is formed by the electrode, i. e. an electron conductor and an electrolyte i. e. an ionic conductor.

***Ideal electrode does not exist:*** electrodes cannot have ideal signal transmission characteristics. Living tissue is a chemically aggressive medium for electrodes: there is always a chemical reaction between the electrode and the tissue.

# DEFINITIONS (CONT.)

- **Recording electrodes** detect bioelectric signals in the peripheral or central nervous system at single cell, local population or macropotential level.
- **Stimulating electrodes** elicit excitation electrically in neural or muscle tissue by charge injection.
- **Brain-computer interface (BCI)** is a system that includes a means for measuring neural signals from the brain, a method/algorithm for decoding these signals and a technique for using this decoding to control a behavior or action.
- **Biocompatibility:** Implantable medical device do not elicit any undesirable local or systemic effects in the human body
- **Biostability:** implanted material should be stable and must be able to withstand attack from a harsh ionic body environment.

Neuroprosthetics is integrating different fields of medical and engineering disciplines. New discoveries in neuroproschetics are always the result of close collaboration of experts in most different areas of research.

**Related areas:**

**Neuroscience** dechiphers the neural codes in sensory systems reveals central representation of motor control commands. Understanding bioelectric signals needs complex signal analysis techniques to isolate action potentials of single neruons, to extract useful parameters from field potentials and EEG type activity.

**Material science** is essential to supply materials suitable for encapsulation of pacemakers, to find better biocompatible electrode materials by developing new conducting polymers.

**Electrochemistry** reveals complex processes at the electrode tissue interface.

**Engineering sciences** developed the electrode arrays recently successfully used in human subjects. Micromaschining of micromechanical systems (MEMS) technology opened new vistas in sensor as well as actuator technology. Miniaturization of electrical circuits, large scale integrated circuits made possible production of implantable devices like hearing prostheses.

**Mathematical and computer sciences** were essential in developing complex signal analysis methods and all the prostheses contain microprocessors with special purpose software.

These were only examples. Neuroprosthetics is a rather new discipline. It has been grown at a tremendous rate in the last decade. Some products are successfully applied in everyday practice like cochlear implants. Others are in experimental or clinical trial phase. In the course we intend to give a survey of divergent areas of neuroprosthetics.

# LECTURES OF THE COURSE:

1. Introduction
2. Physiological basis of electrical stimulation
3. Functional electrical stimulation
4. Stereotaxic technique, electrode implantation
5. Deep brain stimulation
6. Transcranial magnetic stimulation
7. Cochlear functin, implantable hearing aids
8. Cochlear processes
9. Retinal prostheses
10. Physiological basis of brain-computer interface
11. Prostheses working on EEG and single cell principle
12. Perspectives of brain-machine interface

# HISTORICAL MILESTONES IN NEUROBIOLOGY OF ELECTRICAL STIMULATION AND NEUROPROSTHETICS

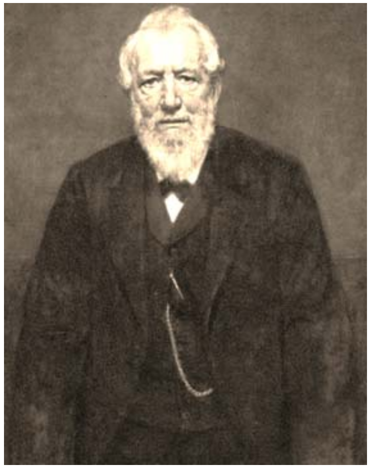
Since the dispute of Galvani and Volta on „animal electricity” at the end of XVIII. century, the close link between nervous processes and electricity became generally known. Perhaps Aldini, the nephew and assistant of Galvani, was the first who demonstrated for the public in cadavers that electrical stimulation induce muscle twitches.

**Luigi Galvani** (1737-1798)

**AlessandroVolta** (1745-1827)

**GiovanniAldini** (1762-1834)

In the XIX. century series of famous neurophysiologists revealed at the available technical level the basic neural processes by electrical stimulation in acute animal experiments. Matteucci with his experiments he proved unequivocally, that the living organism can truly generate electric signals, Du Bois-Reymond can be regarded as the founder of the experimental electrophysiology, Helmholtz was the first who measured the nerve conduction velocity in frog nerve.

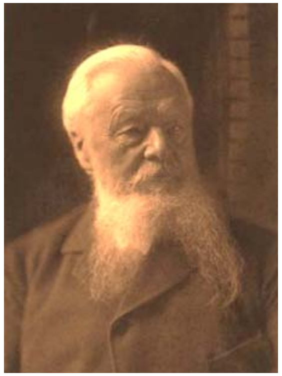


**CarloMateucci** (1811-1868) **Emil du Bois-Reymond** (1818-1896) **HermannL. F. von Helmholtz** (1820-1894)

In the second part of the XIX. century already great diversity of devices and techniques were used in the general practice to carry out single or repetitive electrical stimulations through the skin to alleviate pain and cure different diseases. These can be regarded as early antecedents of the present transdermal electrical nerve stimulation (TENS) and functional electrical stimulation (FES).

The pioneering work of first mapping the neocortex by electrical stimulation in dogs was carried out in the 1870s by two German scientists Fritsch and Hitzig. Their work was continued by Ferrier, who systematically studied the cortical areas of dogs and monkeys and inspired modern neurosurgery.

**Eduard Hitzig** (1838-1907)



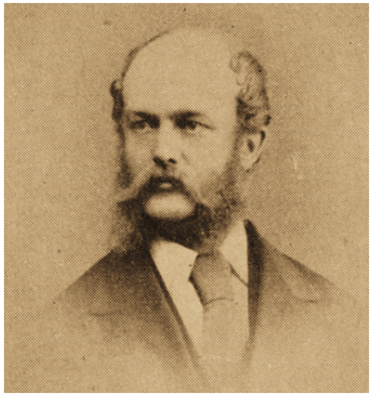
**Gustav Fritsch** (1838-1927)

**David Ferrier** (1843-1924)

Richard Caton was the first who recorded bioelectric signals from the exposed cerebral cortex of cats, monkeys and rabbits in 1875. Independent of his findings, in the next decade others also demonstrated brain electrical potential changes in different species (Danyilevszkij, Beck, von Marxow).

Human electroencephalogram was first recorded by the Jena psychiatrist Hans Berger. He discovered and named the first brain rhythms: the alpha activity appears in a relaxed, but alert state, when the eyes are closed. It disappears and are repleaced by faster beta rhythm at eye opening or when counting or other mental activities are performed. EEG is one of the brain electrical signal used in brain- computer interface.

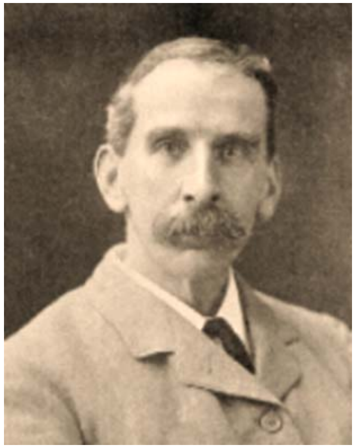
**Richard Caton**
(1842-1926)



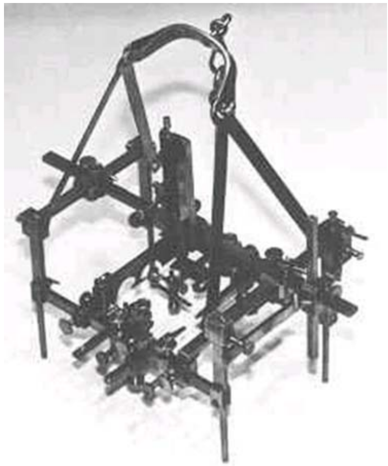
**Hans Berger**
(1873-1941)

In the first half of XX. century Nobel prices were given to electrophysiologists for the discoveries in neural membrane processes and nerve conduction (Nernst, Adrian and Sherrington, Erlanger and Gasser), developing new recording techniques (Einthoven).

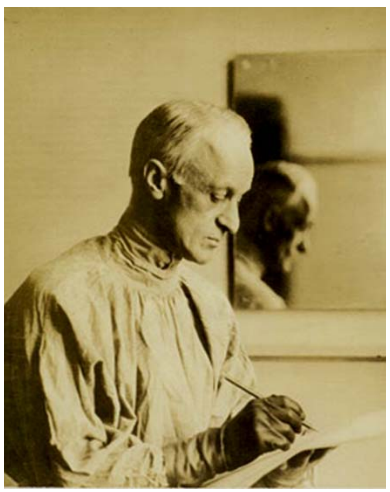
In 1908 the British physiologist and surgeon Sir Victor A. H. Horsley (1857-1916) and his colleague Robert Clarke invented the stereotaxic method that made possible mapping of the subcortical structures in animals and later on opened the way for neurosurgical implantation of electrodes in humans that led to the success story of deep brain stimulation.



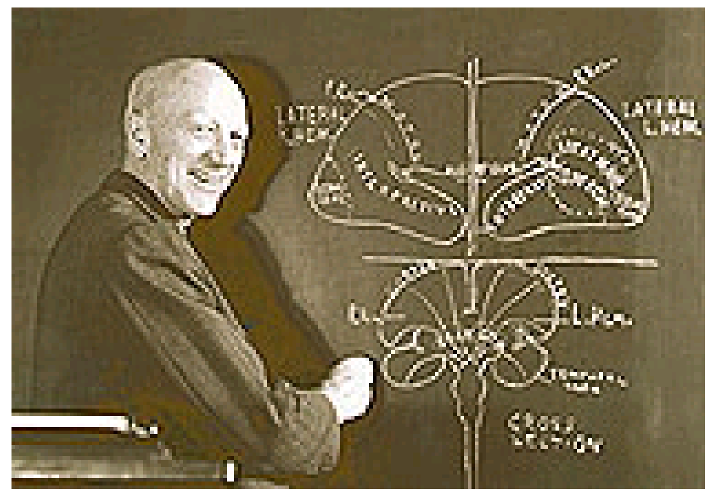
**Victor Horsley**
(1857-1916)
and his stereotaxic frame



Development in neurosurgical techniques resulted in the use of intraoperativ electrical stimulation to map cortical functions and localize epileptic focus. The founder of modern neurosurgery was Cushing and his student Penfield carried out at that time revolutionary studies by electrical stimulation of the neocortex in awake patients during surgery. Stimulating the temporal lobes (the lower parts of the brain on each side) he could elicit meaningful, integrated responses such as memory, including sound, movement, and color.



Harvey W. Cushing (1869-1939)



Wilder G. Penfield (1891-1976),

Walter Rudolf Hess was awarded with the Nobel Prize in Physiology or Medicine in 1949 for mapping the areas of the brain involved in the control of internal organs. Hess was the first who implanted stimulating electrodes into the depth of the brain of cats. He carried out chronic experiments stimulating the diencephalon of the animals. He could induce complex behavioral responses like feeding and rage with concomitant autonomic reactions. James Olds also stimulating the hypothalamus in rats demonstrated the „selfstimulation" phenomenon in the 1950s.

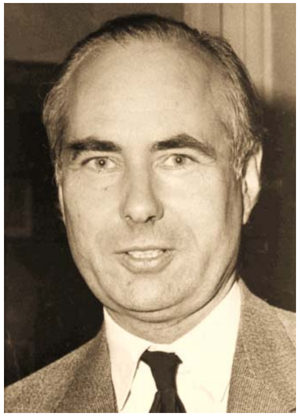
**Walter Rudolf Hess** (1881-1973)

**James Olds** (*1922-1976)*

The Nobel Prize in Physiology in 1963 was awarded jointly to John Carew Eccles, Alan Lloyd Hodgkin and Andrew Fielding Huxley "for their discoveries concerning the ionic mechanisms involved in excitation and inhibition in the peripheral and central portions of the nerve cell membrane".

The membrane properties described by Hodgkin and Huxley serve as basic knowledge for stimulations of nerves and brain structures. Eccles was pioneer of single unit recording that is more and more important in central neuroprostheses.

**Alan L. Hodgkin**
(1914-1998)



**Andrew F. Huxley**
(1917-)

**John C. Eccles**
(1903-1997)

# HISTORICAL LANDMARKS IN THE DEVELOPMENT OF COCHLEAR IMPLANTS

The first clinical cochlear electrode was implanted in 1957 by Djourno and Eyriès. The recipient got a single channel device. It helped with lipreading by providing the rhythm of the speech.

In 1970, Robin Michelson, M.D. reported preliminary results of cochlear implantation in three deaf adults implanted with gold wire electrodes.

In 1964, Blair Simmons at Stanford University implanted some recipients with a six-channel device.

In 1961 Dr William House (an otologist), John Doyle (a neurosurgeon) and James Doyle (an electrical engineer) commenced work on a single-channel device.

In 1972, a speech processor was developed to interface with the House 3M single-electrode implant and was the first to be commercially marketed.

# HISTORICAL LANDMARKS IN THE DEVELOPMENT OF COCHLEAR IMPLANTS 2

In 1978 Australian prototype bionic ear was implanted into the first patient.

In 1984 the FDA formally approved the House 3M device.

In 1984 in Australia Clark and colleagues developed a multi-channel cochlear implant "Nucleus Multi-channel Cochlear Implant„ with F0/F2 1985 F0/F1/F2 strategy.

In 1985 the Nucleus developed the „wearable speech processor" (WSP) strategy.

In 1989 Ingeborg and Erwin Hochmair founded MED-EL, producer of hearing implants, in Austria.

In 1990 the FDA lowered the approved age for implantation to two years.

In 2005 the first totally implantable cochlear implant, in Australia.

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# REVIEW QUESTIONS:

- What is neuroprosthetics?
- Who was the first to map the neocortex by electrical stimulation?
- What is the brain-computer interface?
- Who got Nobel Price for brain electrical stimulation?
- What is selfstimulation and who described it?