



**PETER PAZMANY
CATHOLIC UNIVERSITY**



**SEMMELWEIS
UNIVERSITY**



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

Consortium leader

PETER PAZMANY CATHOLIC UNIVERSITY

Consortium members

SEMMELWEIS UNIVERSITY, DIALOG CAMPUS PUBLISHER

The Project has been realised with the support of the European Union and has been co-financed by the European Social Fund ***

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

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



Nemzeti Fejlesztési Ügynökség

ÚMFT infóvonal: 06 40 638 638

info@nfu.hu • www.nfu.hu

TÁMOP – 4.1.2-08/2/A/KMR-2009-0006



BEVEZETÉS A FUNKCIONÁLIS NEUROBIOLÓGIÁBA

INTRODUCTION TO FUNCTIONAL NEUROBIOLOGY

By Imre Kalló

Contributed by: Tamás Freund, Zsolt Liposits, Zoltán Nusser, László Acsády, Szabolcs Káli, József Haller, Zsófia Maglóczky, Nórbert Hájos, Emilia Madarász, György Karmos, Miklós Palkovits, Anita Kamondi, Lóránd Eröss, Róbert Gábrriel, Kisvárdai Zoltán

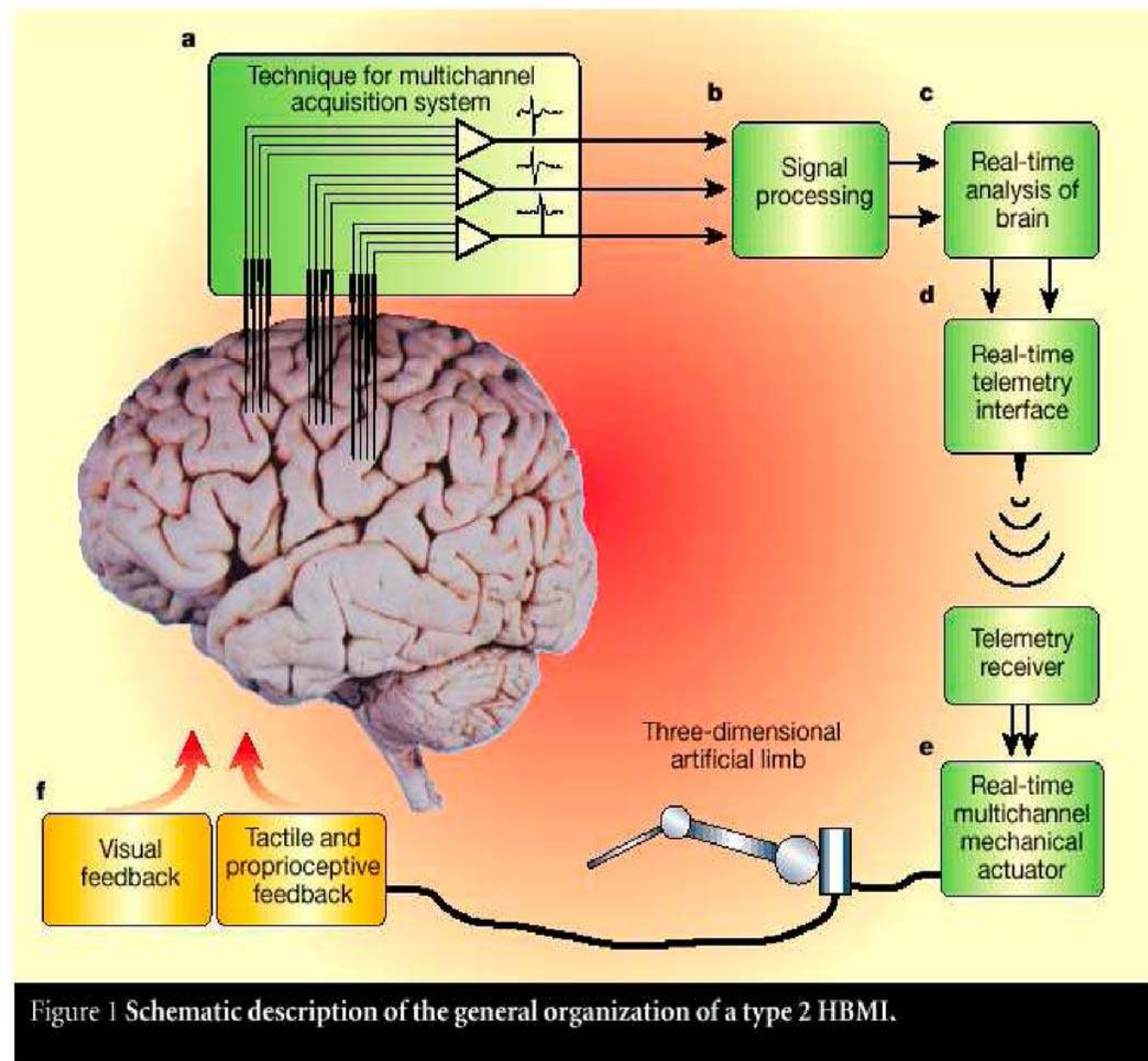
Brain-machine interfaces

Szabolcs Káli

Pázmány Péter Catholic University, Faculty of Information Technology

*Infobionic and Neurobiological Plasticity Research Group, Hungarian Academy of Sciences –
Pázmány Péter Catholic University – Semmelweis University*

Brain-machine interfaces



Applications, goals

- Controlling machines directly with the brain
 - For injured (paralyzed) persons: robot limb, computer cursor, moving own muscles
- Direct stimulation of the brain, bypassing sensory organs
 - For blind, deaf, etc. persons
 - Input extra information

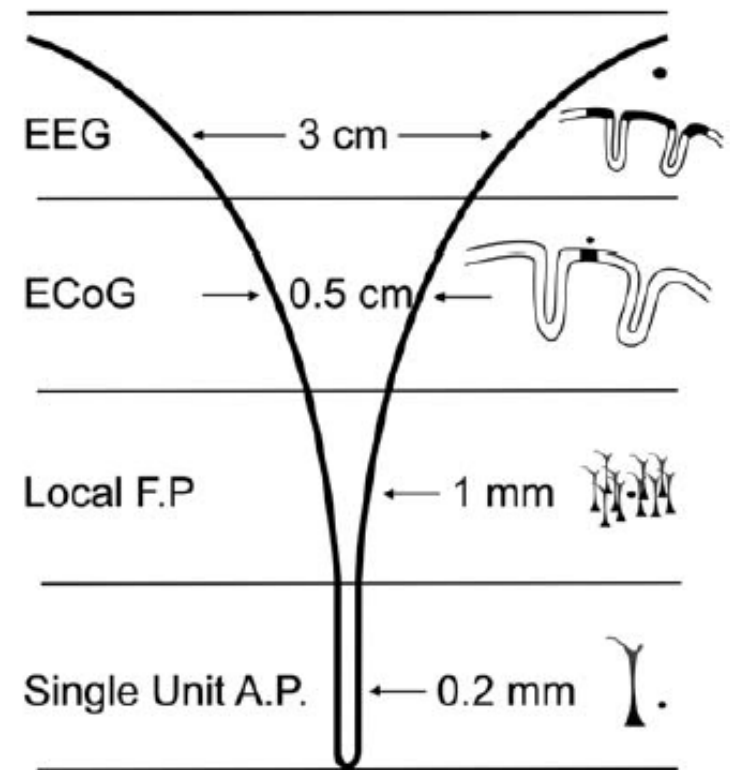
Tools – recording neural activity

a) Non-invasive technologies

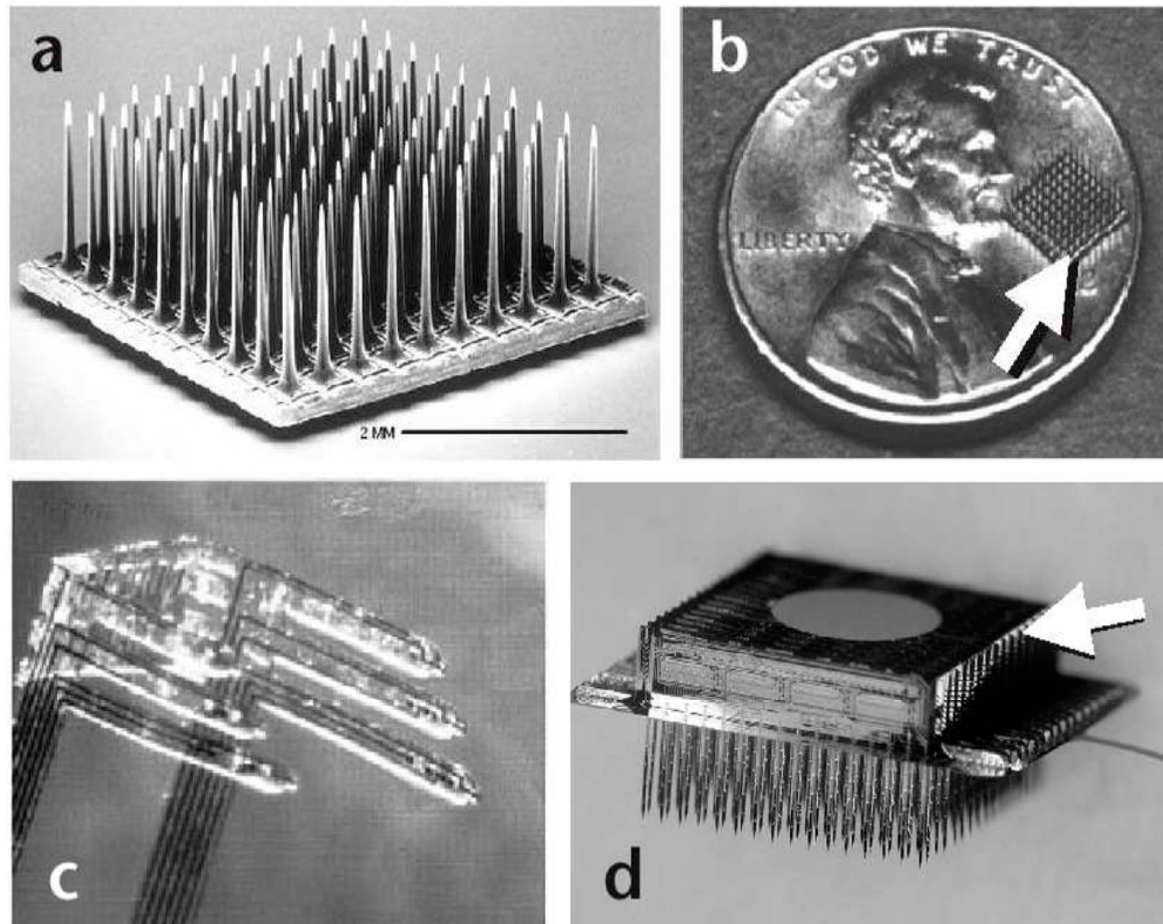
- Electro-encephalogram (EEG),
Magnetoencephalography (MEG)
(Synchronous activity of 100 million neurons!)

b) Chronically implanted electrodes in the brain

- Electro-corticogram (ECoG) (recorded from the surface of the cortex, better spatial and temporal resolution)
- Local field potential (LFP)
- „Multi-unit” activity (MUA)
- Single unit action potentials



Tools – implanted electrodes



Picture: Techniques for multiple, parallel single-cell recordings.

Picture A: Silicon electrode array containing 100 microelectrodes. B: Size comparison to a coin.

C: Polyamide electrode array

D: 256-shank electrode array with 1024 recording sites and an integrated circuit for signal processing.

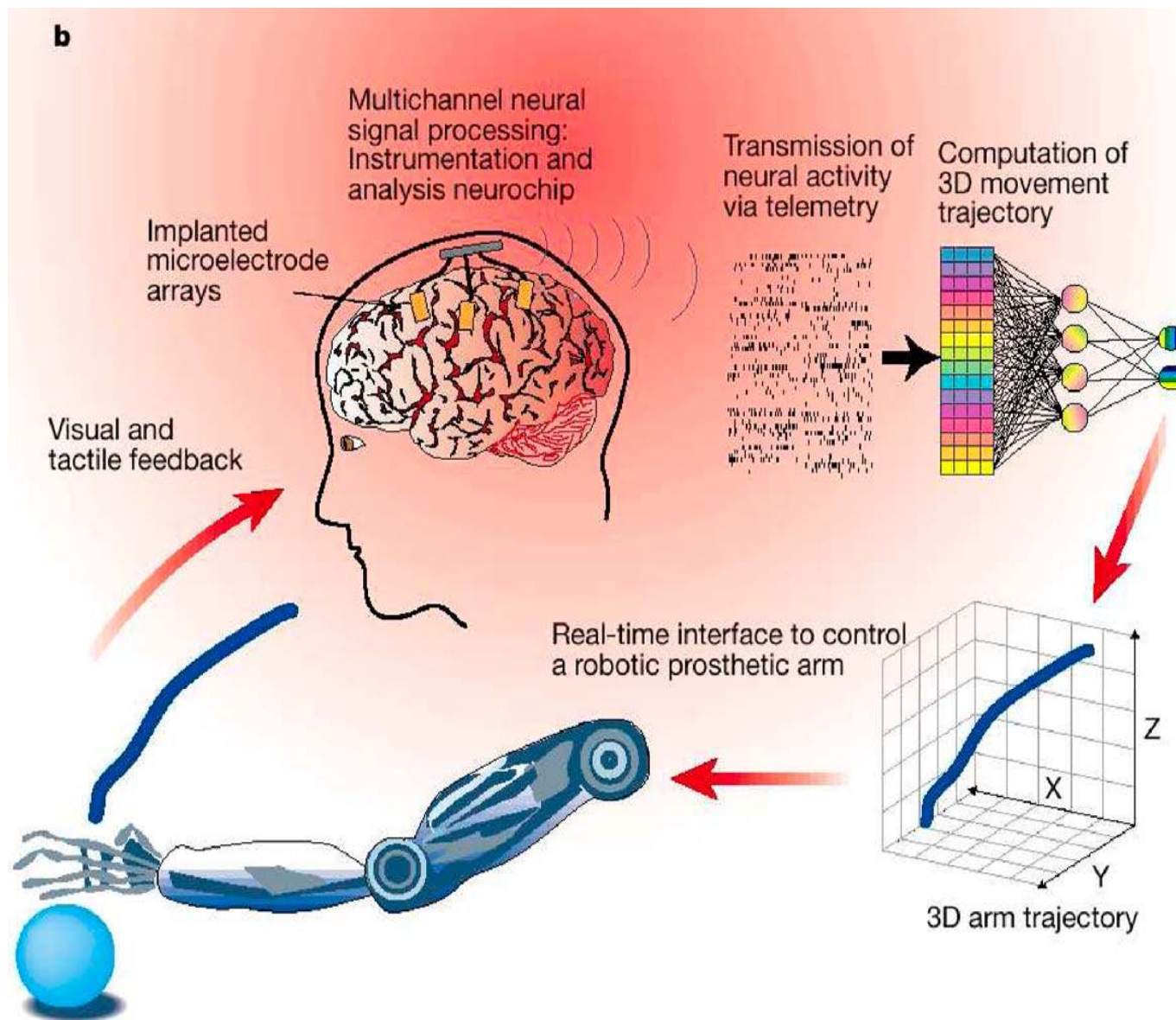
Tools – Stimulating the brain

- a) Non-invasive: nonspecific, affects large parts of the brain.
 - Magnetic stimulation through the skull (transcranial magnetic stimulation, TMS): Uses electromagnetic induction to induce electric currents. It is tested as a treatment tool for various neurological and psychiatric disorders.
- b) With implanted electrodes
 - Selective microstimulation: Affects a relatively small number of neurons. Example (Fitzsimmons et al., 2007): Microstimulation of the primary somatosensory cortex in monkeys. Reward for discriminating between stimulus patterns, over 90% success rate after training.
 - Another example (Brecht et al., 2004): Intracellular stimulation of a single pyramidal cell in rat motor cortex can evoke whisker movement. The number of action potentials determines the latency to the onset of movement, and action potential frequency determines whisker movement direction and amplitude.

Results to date

- 1) Recordings from different (motor) cortical areas, used for moving robotic tools.
 - Basic observation: population code („population vector”)
 - Nicolelis group:
 - Parallel recordings in monkeys and rats from multiple areas (30-100 neurons).
 - Acquisition of motor parameters with linear prediction techniques and artificial neural networks.
 - Moving a robotic limb in 3D and 1D by on-line prediction of movement, during multiple exercises.

Results to date

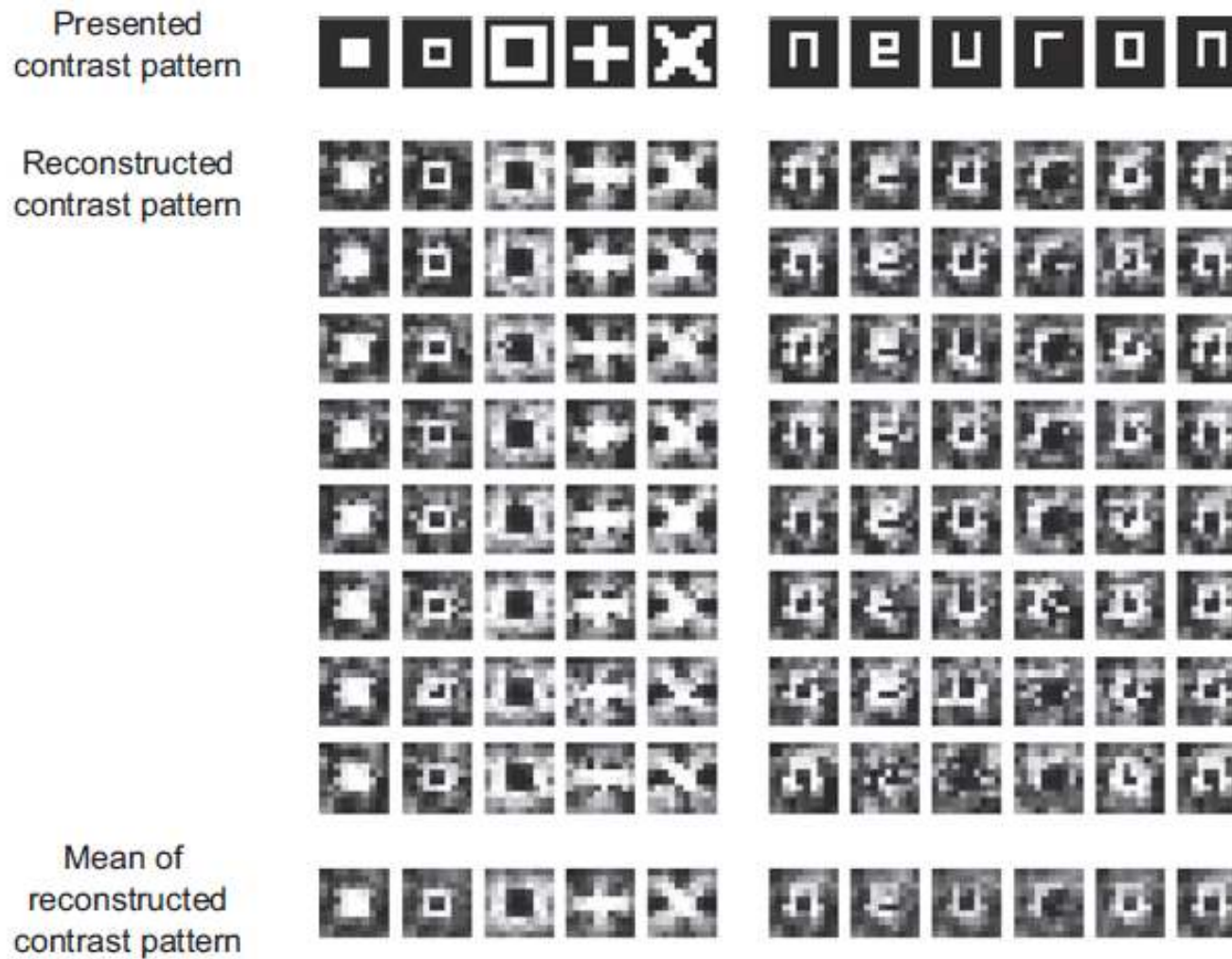


Results to date

- Schwartz, Donoghue, Nicolelis groups:
 - Closed loop system, with visual feedback
 - Efficiency improves with training
 - Firing behaviors of neurons change
 - After training the robotic arm can be moved without muscle movement
- LFP can be used for prediction too, and works better when combined with MUA or SUA.
- In humans: Controlling of EEG slow cortical potentials can be learned – „mind-controlled typewriter” (with a series of binary choices)

Results to date

Yoichi Miyawaki et al.: Visual image reconstruction from V1 and V2 fMRI recordings.



Goal-oriented control of robotic arm

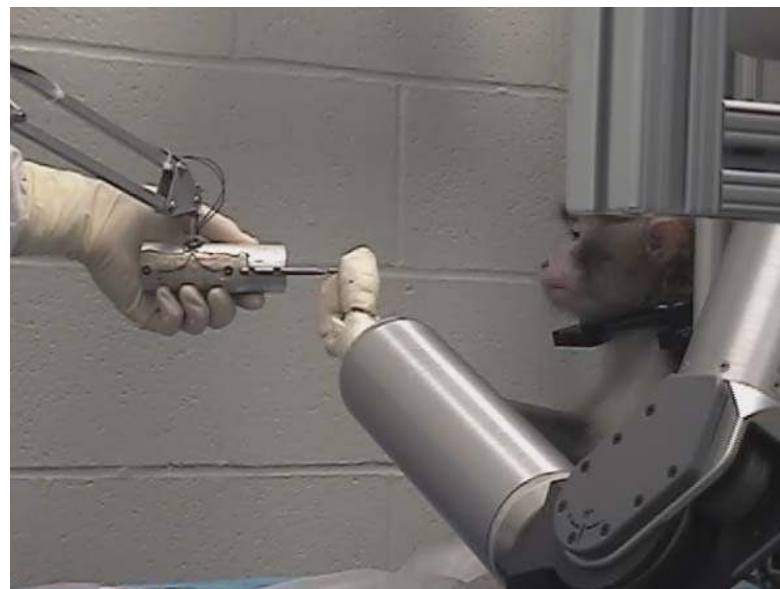
- Velliste et al. (2008): Monkeys control a robot arm with motor cortical activity in a self-feeding task
- The robot arm has two joints, and a gripper at the end, and has five degrees of freedom: three at the shoulder, one at the elbow and one at the hand.
- The monkey was restrained, and could control the arm via an implanted microelectrode array in the primary motor cortex.
- Only relatively few neurons were used for the control (typically 15-25 cells.)

Goal-oriented control of robotic arm

1.



2.



3.



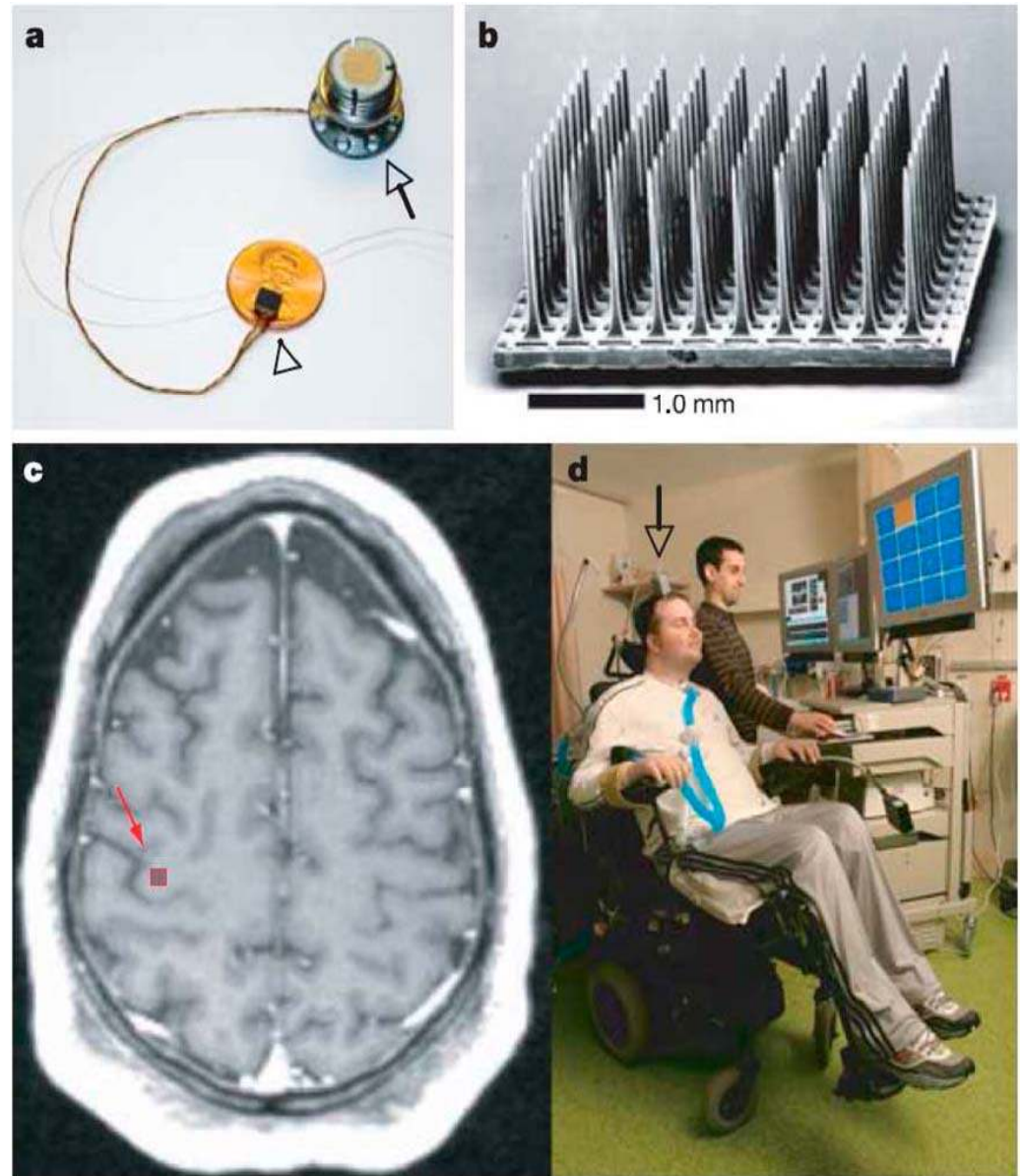
4.



Moving a cursor and a robotic arm (by a human)

Hochberg et al.: Recording primary motor cortex activity with a 96-microelectrode array. The spiking patterns were generated by intended hand movement. The recorded information was decoded, and the patient could accomplish multiple tasks:

- Moving a computer cursor in 2D.
- Opening and closing a prosthetic hand.
- Operating a remote control, even while conversing.



Results to date – direct stimulation of neurons

a) For substituting sensory organs

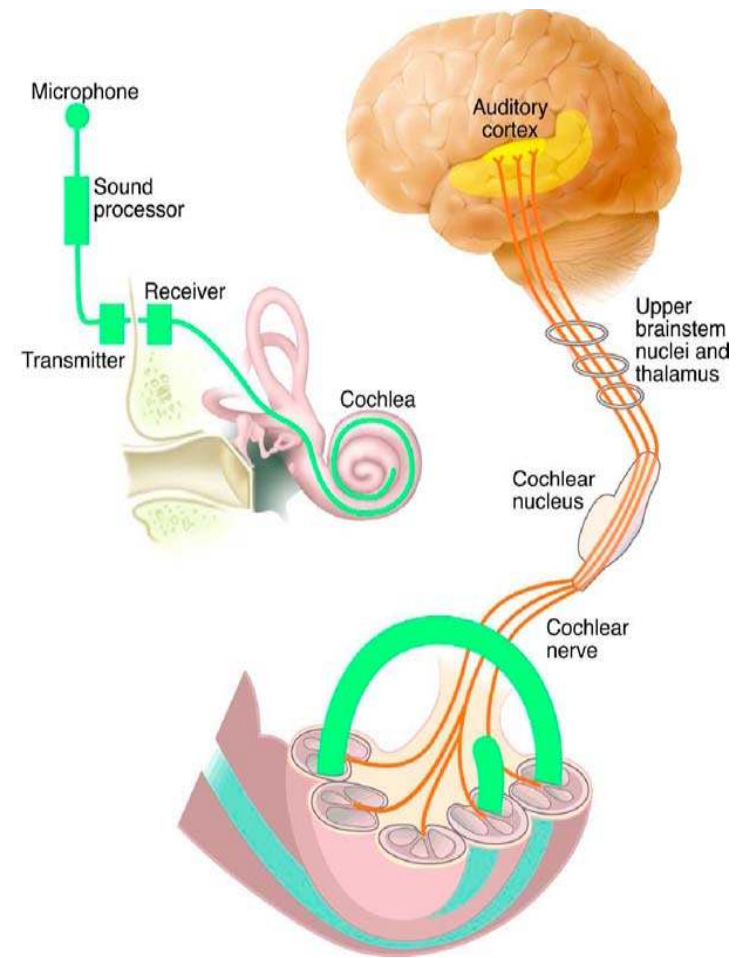
- Cochlear implants are widely used, and consist of:

External parts:

- Microphone to pick up sound
- Sound processor to filter and split sound into channels
- A transmitter, which transmits power and sound signals by electromagnetic induction

Internal parts:

- A receiver, which receives the signal of the transmitter
- An array of electrodes (up to 24), which sends impulses to the cochlear nerve. The cochlea is mapped topologically according to the sound frequency, with the recorded frequency decreasing as one moves further from the apex.



Results to date – direct stimulation of neurons

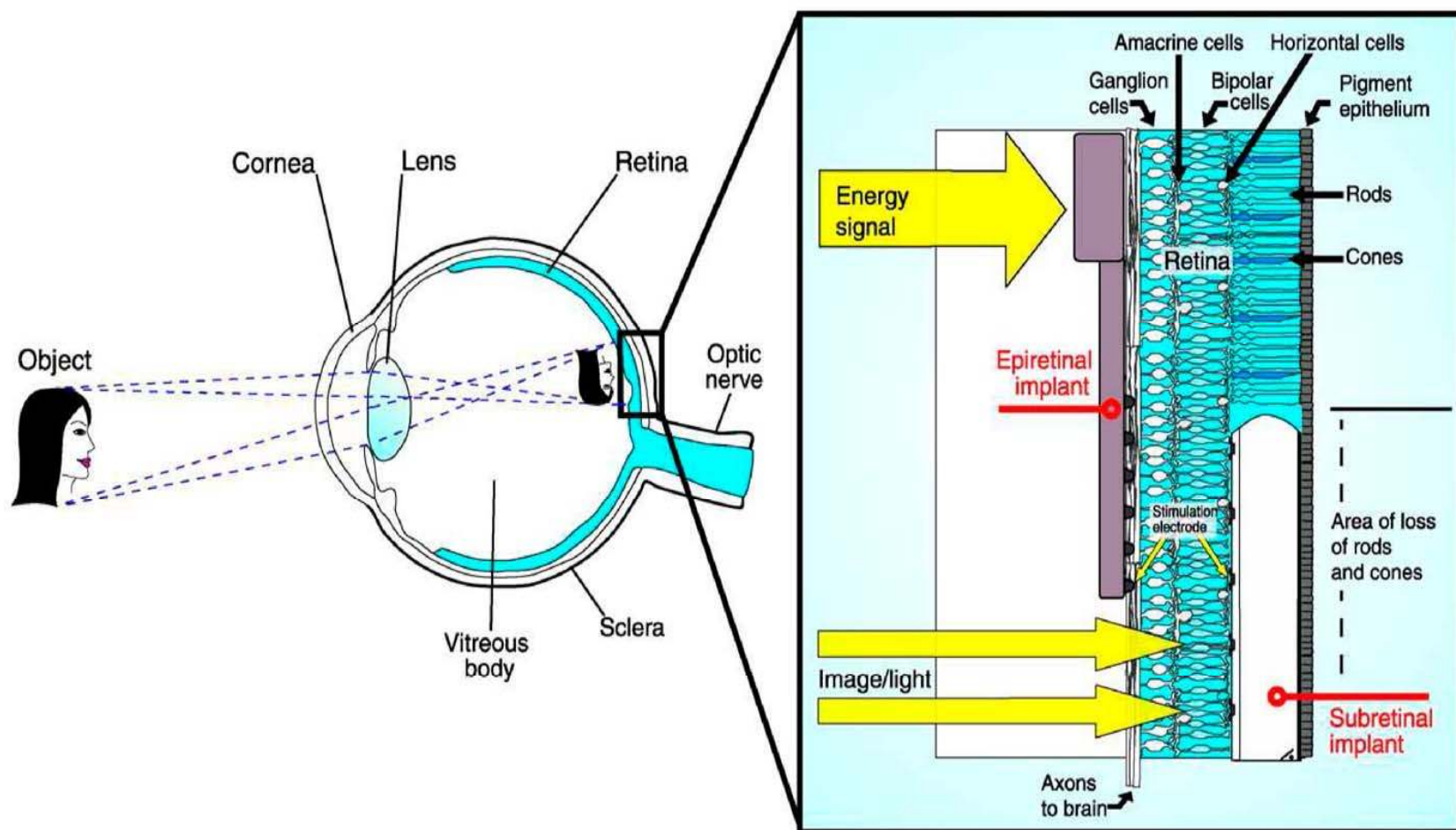
Retinal implants – initial successes (if only photoreceptors are missing)

Two types:

- Subretinal implant:
 - Rods and cones are replaced by a silicon plate with thousands of light-sensitive photodiodes, where each diode is equipped with a stimulation electrode.
 - Light on the diodes causes the electrodes to inject current into the remaining (non-photoreceptor) neurons in the retina.
- Epiretinal implant:
 - Has no light-sensitive diodes, but receives signal from a camera outside the body.
 - Electrodes directly stimulate the ganglion cells, whose axons transmit information to the brain through the optic nerve.

Results to date – direct stimulation of neurons

Schematics of epiretinal and subretinal implants:



Results to date – single cell stimulation

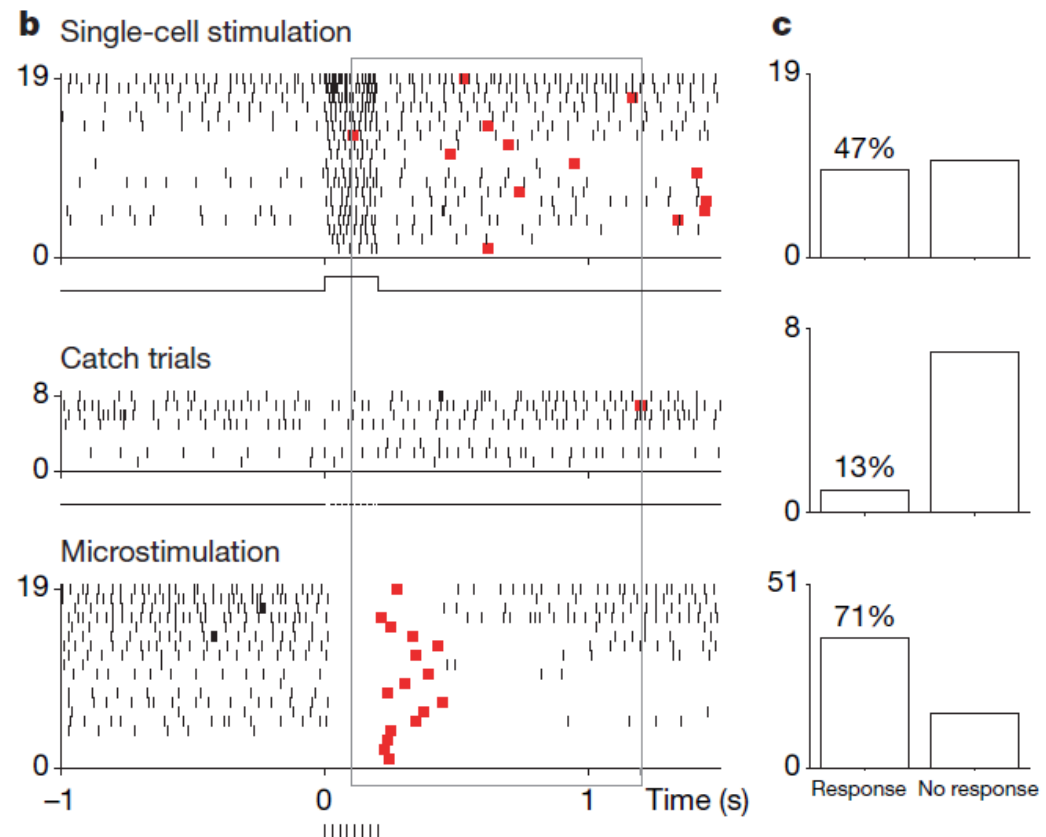
Houweling et al. (2008): Training of rats by giving reward for responding to low intensity microstimulation of barrel cortex (part of the rat somatosensory cortex which detects whisker movements.)

Picture: After training animals responded to single-cell stimulation.
Left column: Responses to single cell stimulation, microstimulation and catch trials.

ticks: action potentials,
red squares: First response to the stimulation.

Right column: Quantification of responses.

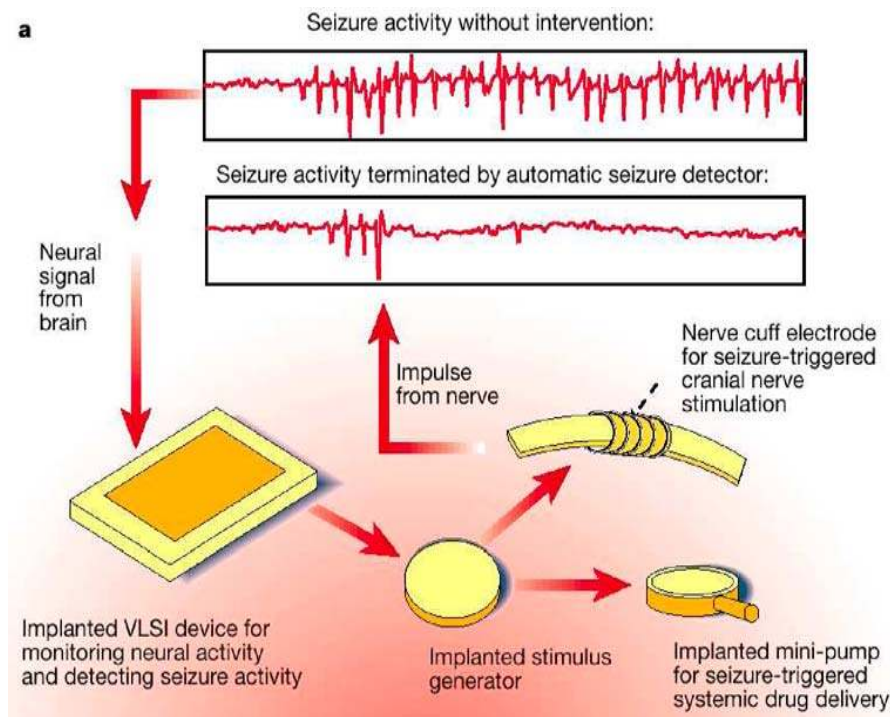
Stimulation of excitatory neurons caused weak biases towards responding, stimulation of inhibitory neurons led to larger sensory effects.



Results to date – direct stimulation

b) For other purposes

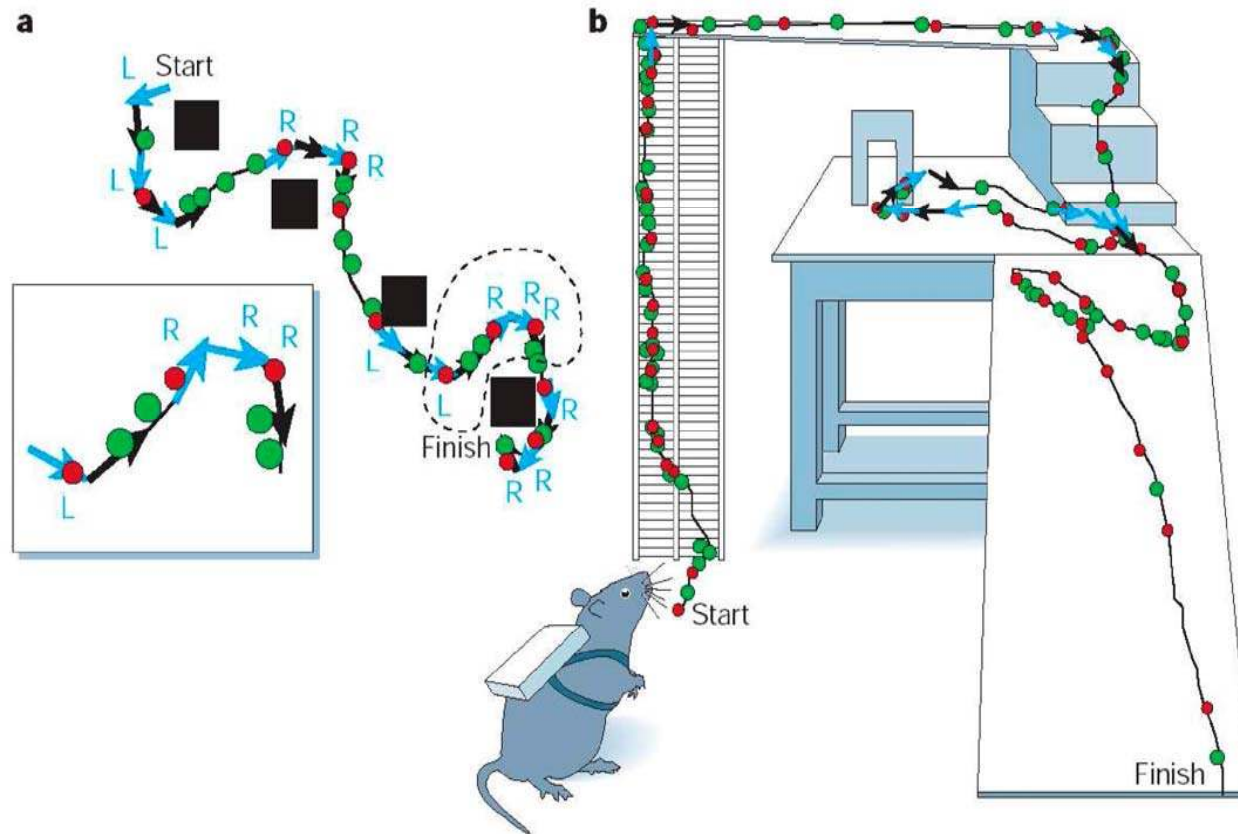
- Symptomatic treatment of Parkinson's disease by stimulating the subthalamic nucleus
- Controlling epilepsy by recording and stimulation:



Acquiring reward as a result of stimulation (self-stimulation experiments)

Results to date – direct stimulation

A combination of these techniques: „remote-controlled rat”



Picture: Rats learned to obtain periodic rewards by running forwards and turning correctly when left- or right-turning cues were issued. Blue arrows: direction when a „turn” command was given, black arrows: direction 1 second after the command. Red dots: head position, green dots: „forward” command.

Problems, tasks

- Control of devices based on neural recordings is closer to the solution, but there are problems with
 - Long-lasting stability (tissue changes, e.g., scars change conductivity, dislocation, equipment failure)
 - Direct muscle stimulation
 - Brain plasticity, and its limits
- Problems with direct brain stimulation:
 - There is no selective technique, especially at population level
 - But, sometimes even one neuron counts (whisker movement in rats can be evoked by stimulating a single motor neuron)