Brain computer interfaces - BCI

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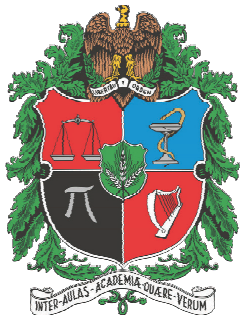
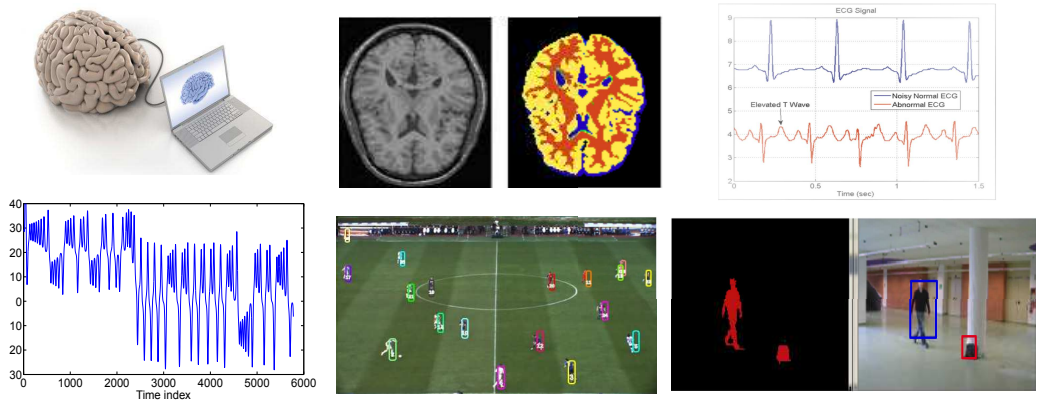


Outline

Outline

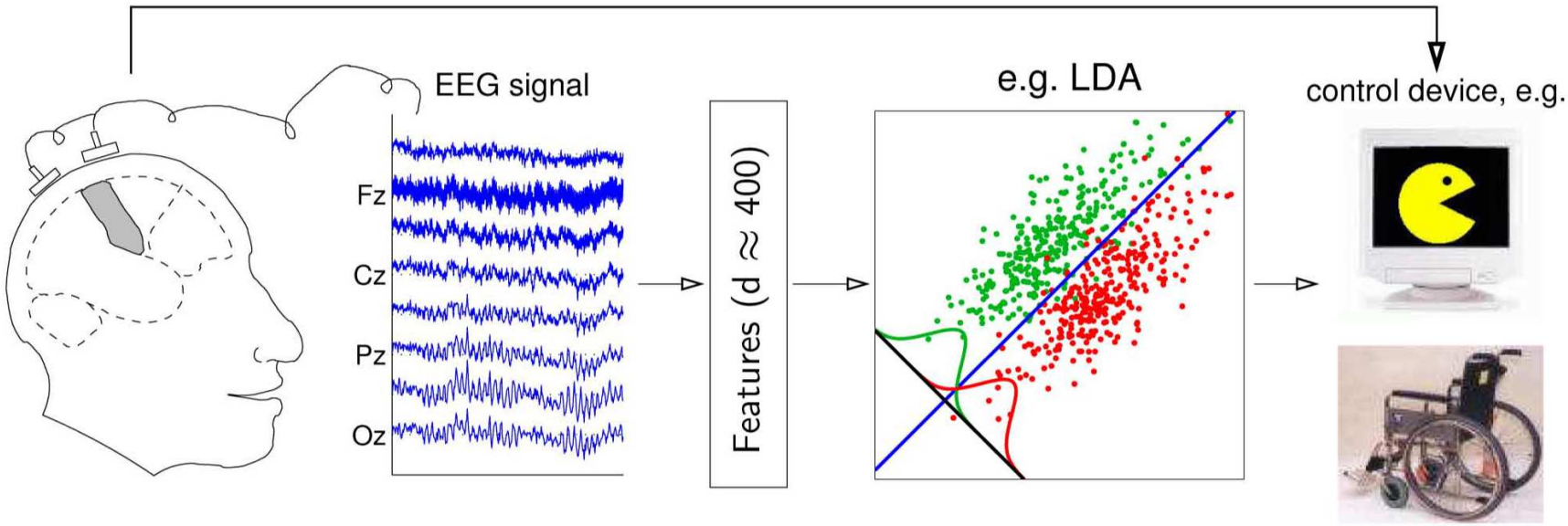
Motivation

- Biomedical signal processing
- Computer vision
- Pattern recognition
- Bioinformatics
- **Brain Computer Interfaces**



Signal processing tools to support
the development of automatic systems

Motivation:
Brain Computer Interfaces (BCI)



source: TU Charite Campus Benjamin Franklin - Machine learning for BCI

BCI: translation of human intentions into a technical control signal without using activity of muscles or peripheral nerves

Motivation:
Brain Computer Interfaces (BCI)

- Assistive care
- Gaming and entertainment
- Cognitive improvement
- Restoring neural and/or behavioral function

BCI has become one of the most interesting alternatives to support automatic systems able to interpret brain functions

Motivation:
BCI interesting remarks

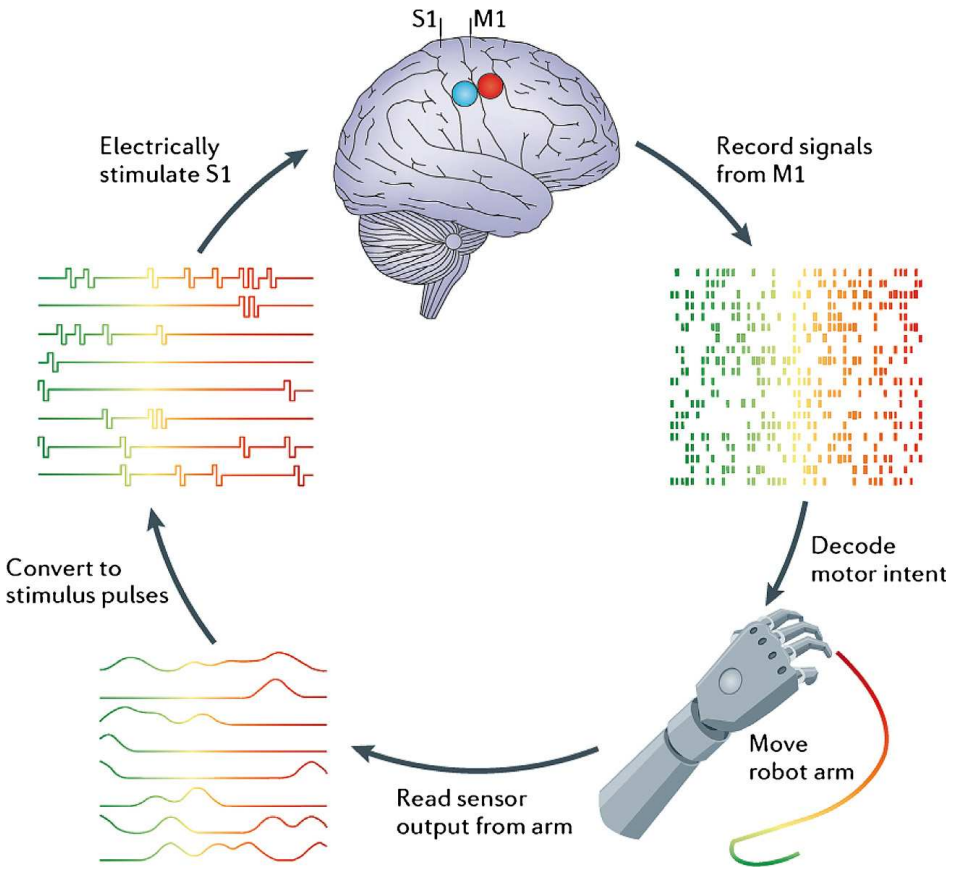
- Grey Walter demonstrated use of **non-invasively brain recordings** from a human subject **to control** a **slide projector** (1964) [Graimann et al., 2010].
- Fetz demonstrated **increase** of the **firing rates** of neurons in the **motor cortex** in non-human primates along with **auditory** or **visual feedback** (1969) [Fetz, 1969].
- BCI was coined by Jaceques Vidal in 1971 aiming to interface human brain with computers (University of California) [Vidal, 1977].

Motivation:
BCI interesting remarks

- The field of BCI has expanded for both **invasive** and **non-invasive** neural recordings in humans and animals.
- Nowadays, both **sensorimotor** and **cognitive functions** are studied, incorporating **feedback** mechanisms in **closed loop systems** [Miranda et al., 2015].

Outline

Idealized bidirectional BCI

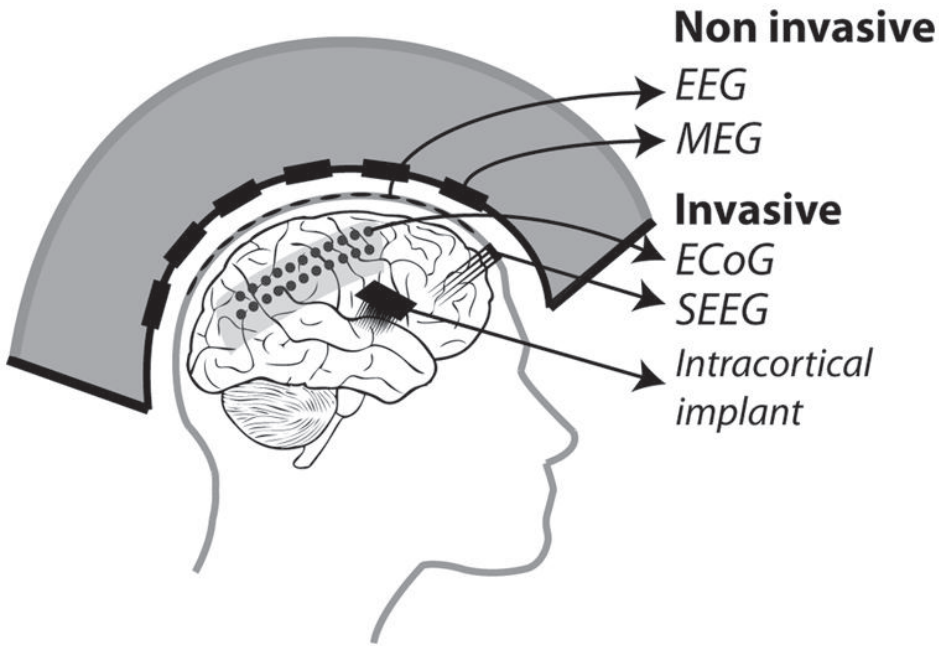


Decoding: extracting information from neural responses

Encoding: representing the information of neural responses

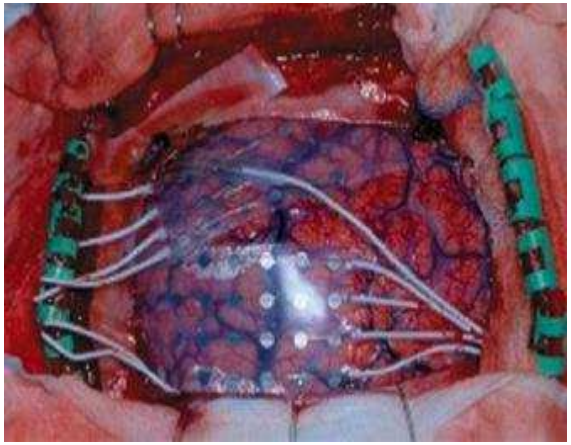
BCI technologies

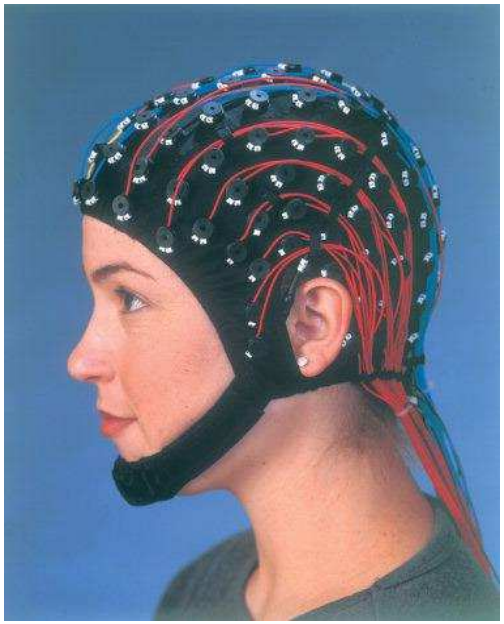
- **Invasive**: detection of *single neuron activity* by intra-cortical electrodes into the gray matter (rats and monkeys).
- **Partially invasive**: recording electrocorticographic (ECoG) implants inside the skull but outside the gray matter.
- **Noninvasive**: recording of the brain activity at a *macro level*.



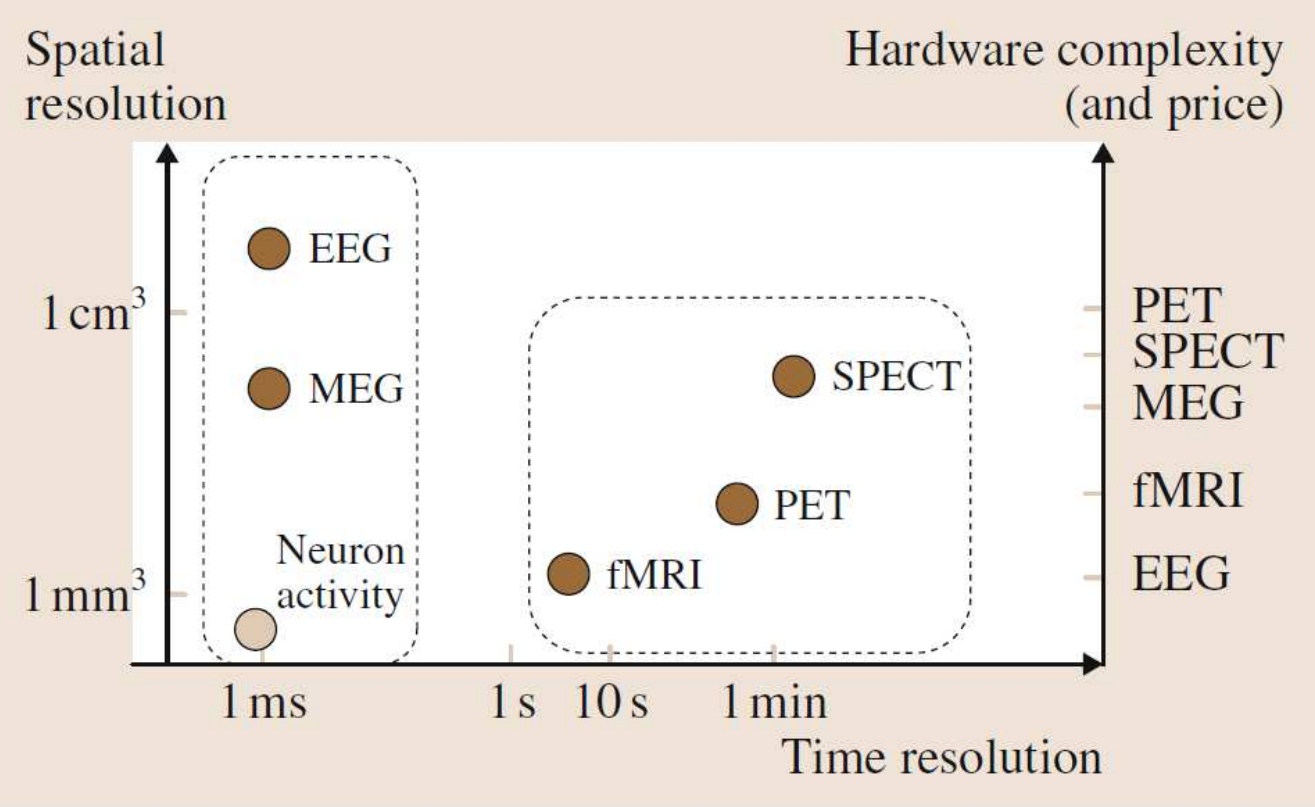
BCI technologies

- **Invasive** techniques are more reliable and less noisy.
  Drawbacks: neurosurgery is required, long-term use or periodical replacement.
- **Noninvasive** are more safe and cheap. Subject preparation is fast being possible to perform real-time analysis.
  Drawbacks: noisy signal, time/spatial resolution issues.



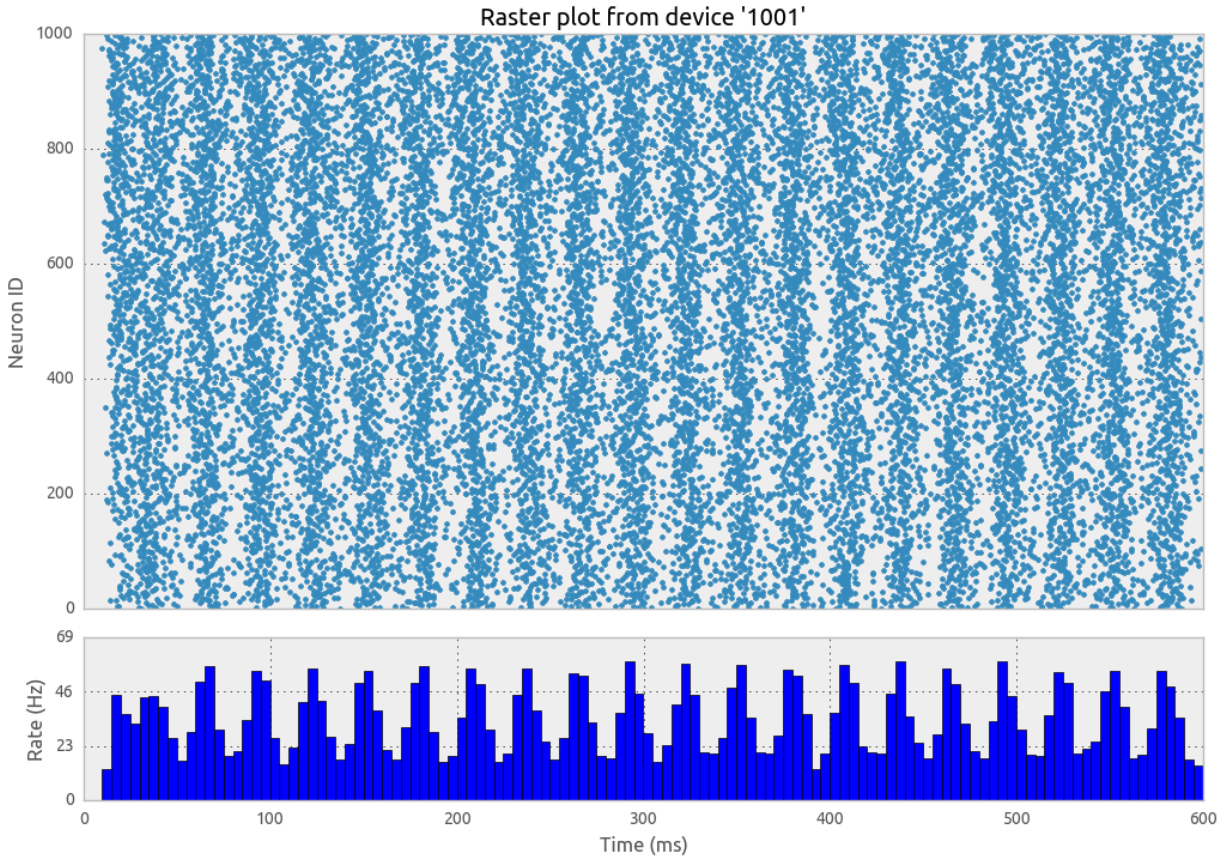


BCI technologies



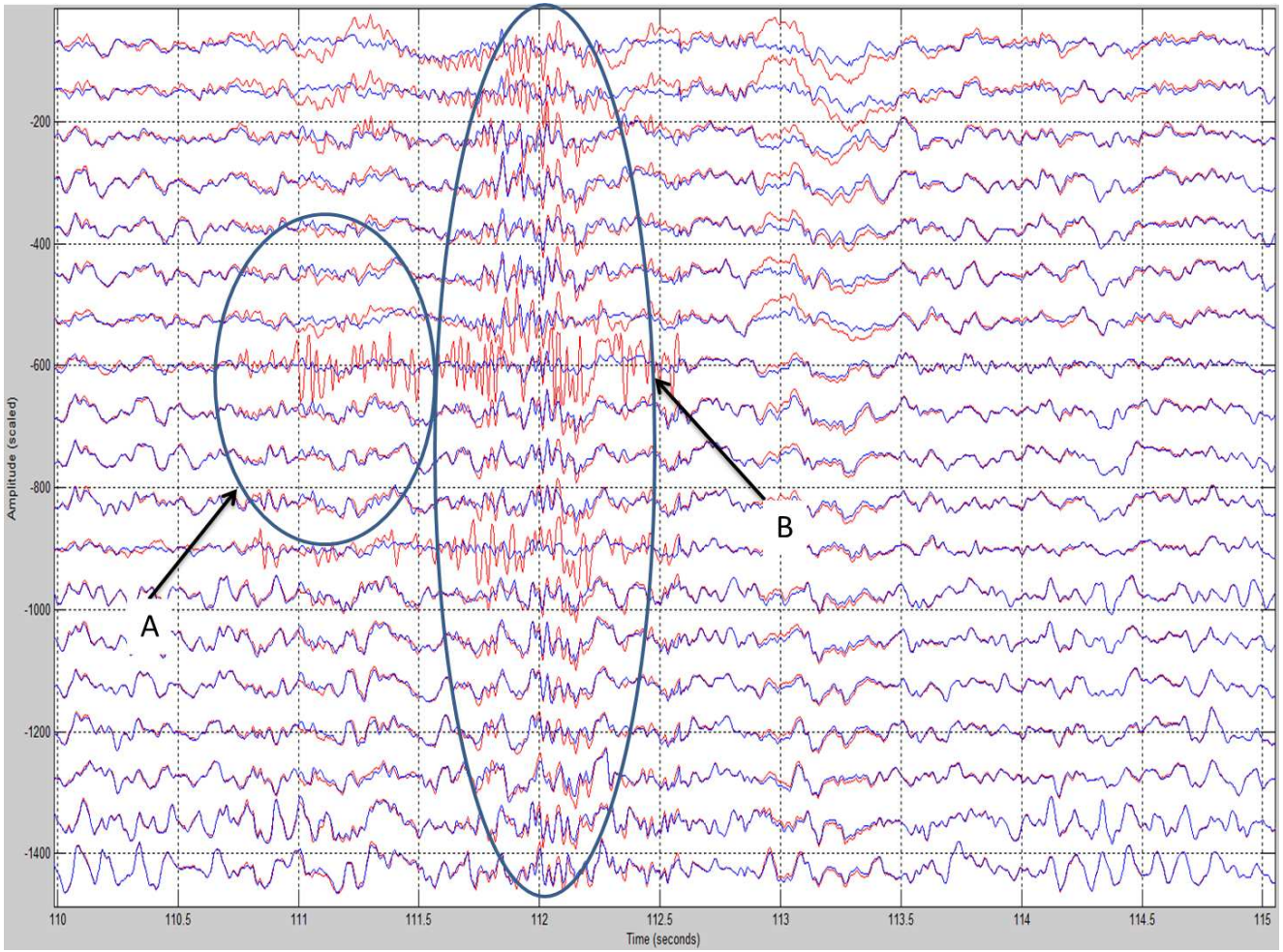
- Neuron activity - micro-array electrodes
- EEG: Electroencephalography
- MEG: magnetoencephalography
- fNIR: functional near-infrared systems
- fMRI: functional magnetic resonance imaging
- SPECT: single photon emission computerized tomography
- PET: positron emission tomography

BCI technologies



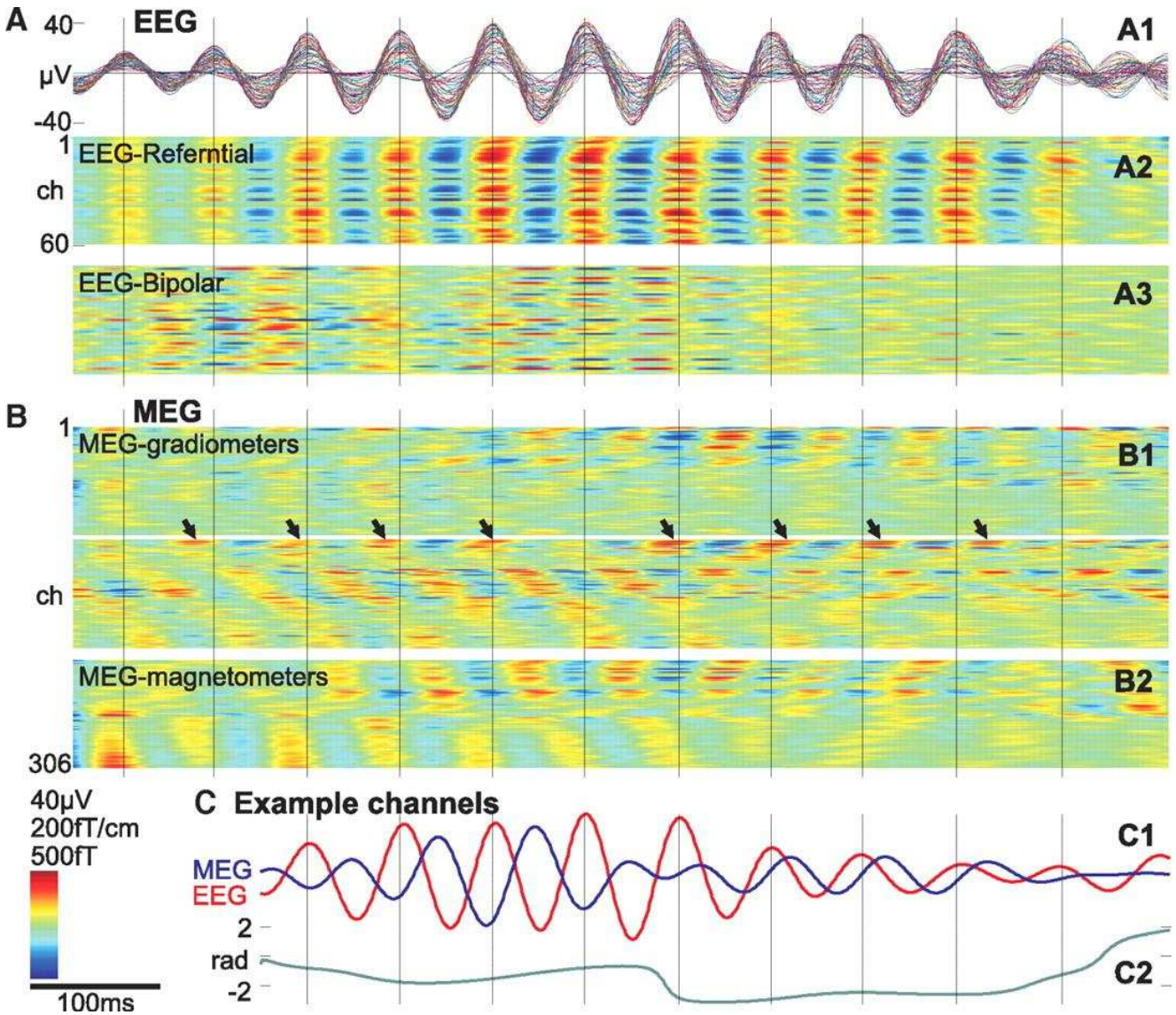
Neuron activity - spikes

BCI technologies



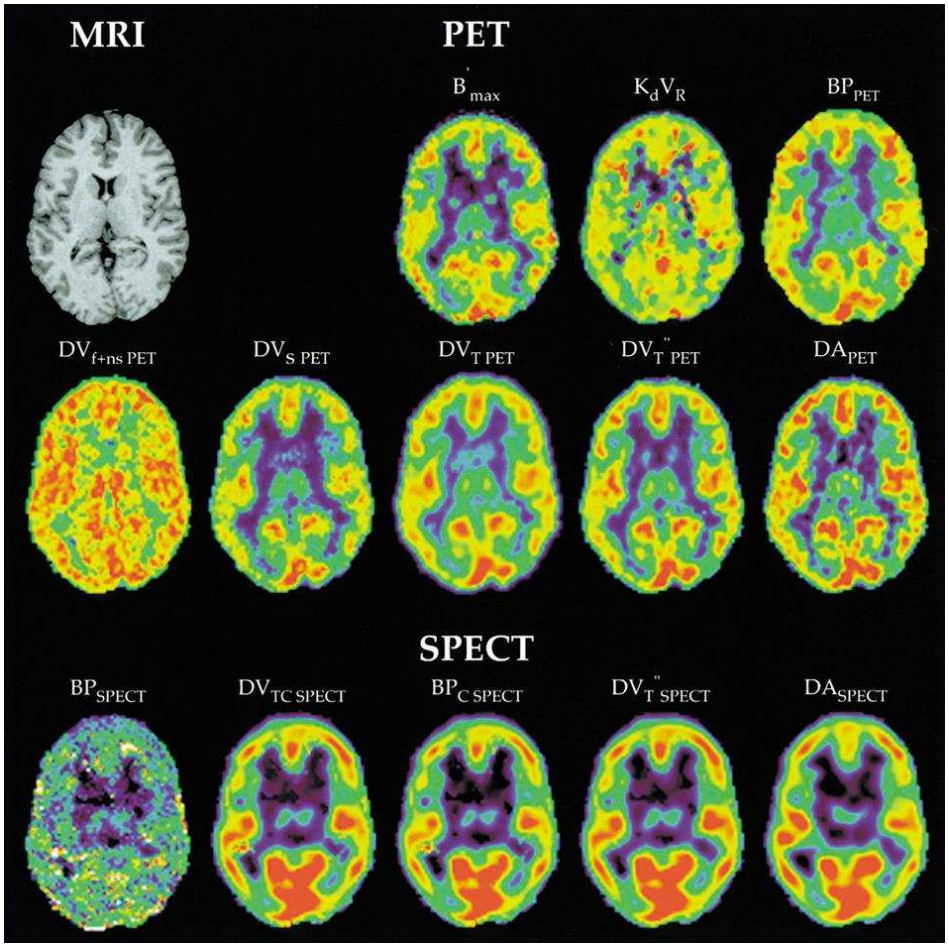
EEG

BCI technologies



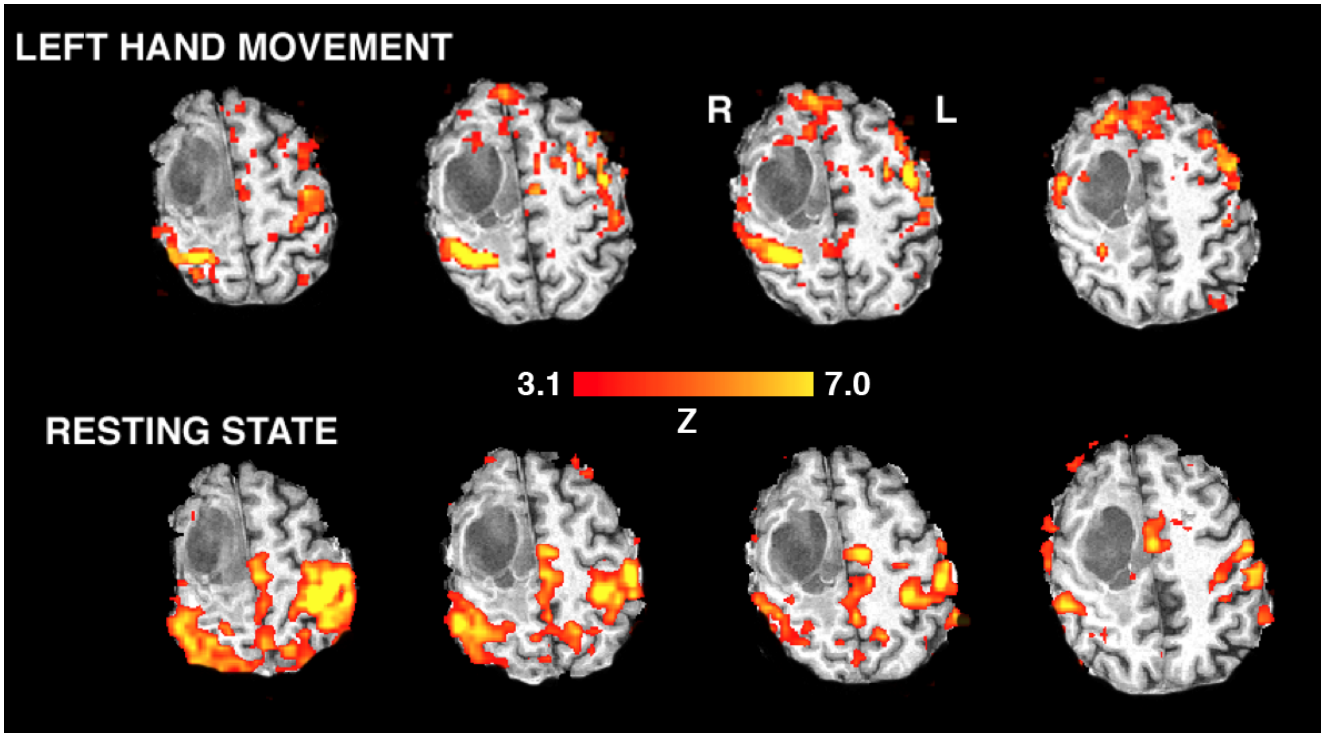
EEG and MEG

BCI technologies



PET and SPECT

BCI technologies



fMRI

BCI technologies

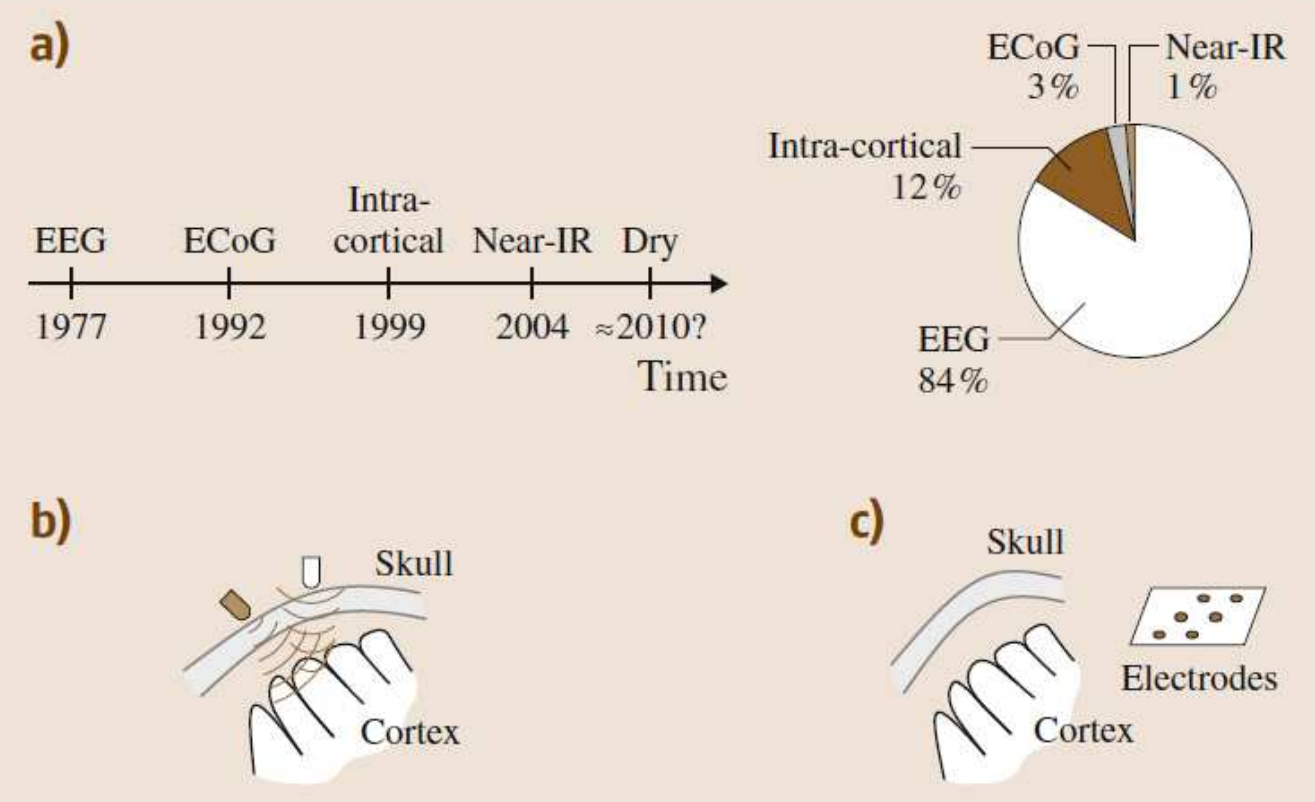
- Micro-array electrodes provide a good temporal and spatial resolution.
  Drawback: expensive, surgery is required.
- EEG has a good temporal resolution.
  Drawback: the worst spatial resolution.
- fMRI closest spatial resolution to the real neuron activity.
  Drawback: too expensive, poor temporal resolution.

BCI technologies

- SPECT and PET do not provide resolution advantages and are expensive.
- fNIR is cheaper than fMRI, however, both of them are based on changes in cerebral blood flow (slow response).
- EEG is the most practical technology for BCI.

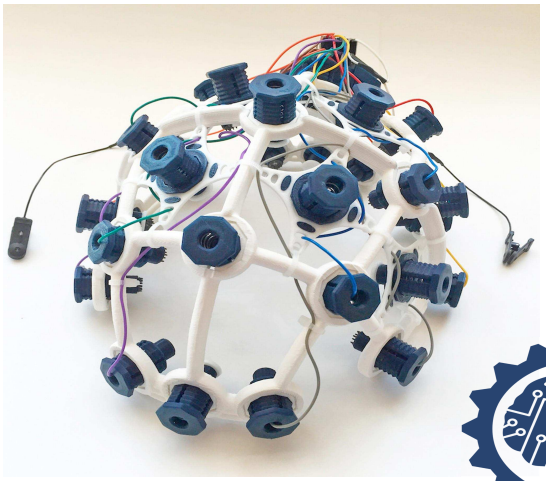
A hybrid BCI could be an interesting alternative (e.g. EEG -fMRI)

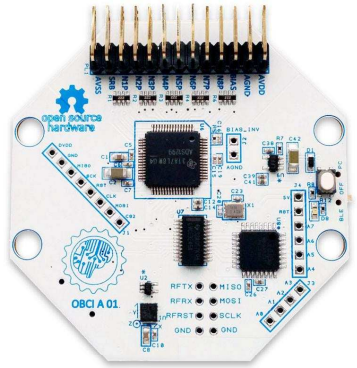
BCI technologies



BCI technologies evolution a) sensor technology, b) invasive sensors, c) noninvasive sensors.

BCI technologies





OpenBCI

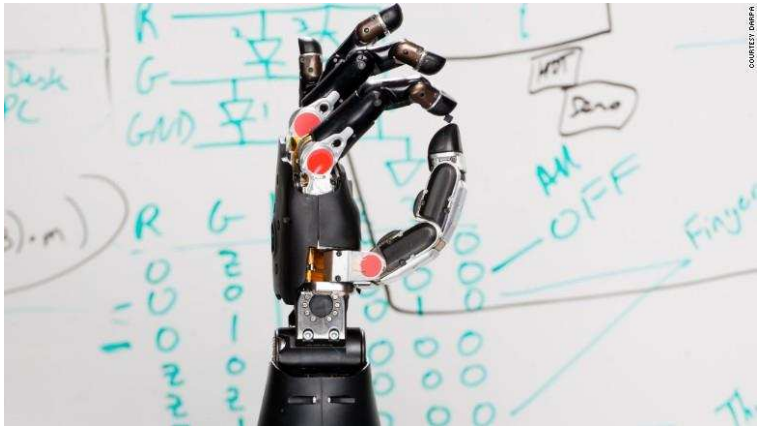
EMOTIV

Cheap EEG sensors

Outline

BCI highlights: DARPA

- The Defense Advanced Research Projects Agency (DARPA) has funded innovative scientific BCI research since the 1970s.
- BCI efforts aimed at **restoring neural** and/or **behavioral function**.
- BCI efforts aimed at **improving human training** and **performance**.
- Promoting interdisciplinary collaborations among researchers, **engineers**, and **clinicians**.



source:http://edition.cnn.com/2015/09/15/health/.html

DARPA BCI projects: main goals

- **Detect** – Develop diagnostics, models, and devices to characterize and mitigate threats to the human brain.
- **Emulate** – Leverage inspiration from functional brain networks to efficiently synthesize information.
- **Restore** – Reestablish behavioral and cognitive function lost as a result of injury to the brain or body.
- **Improve** – Develop brain-in-the loop systems to accelerate training and improve functional behaviors.

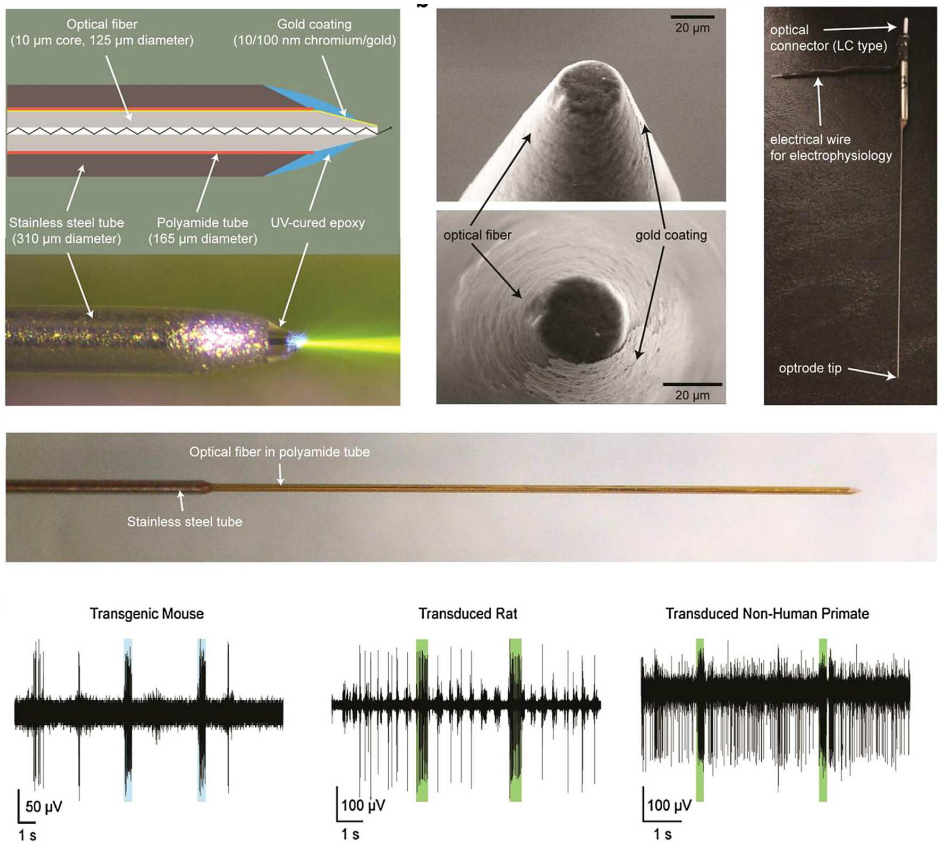
DARPA BCI projects: revolutionizing prosthetics

- The objective was to allow **Wounded Warrior amputees** to **improve quality of life**, maximize function and independence, enable activities of daily living, and return to service.
- Initial measures: inertial, pressure/bumpm electromyogram, implanted myoelectric sensors.
- **Revolutionizing Prosthetics** has provided transformative innovations in **direct brain control** of **prosthetic limbs**.

DARPA BCI projects: reorganization and plasticity to accelerate injury recovery

- Brain function is **not** fixed or **static**.
- Brain's fundamental characteristics –**plasticity**.
- It **adapts** in response to **learning new information** or new **behavioral skills**: e.g., meeting a new person or riding a bicycle.
- Learning process: multiple **spatial** and **temporal** scales.

DARPA BCI projects: reorganization and plasticity to accelerate injury recovery



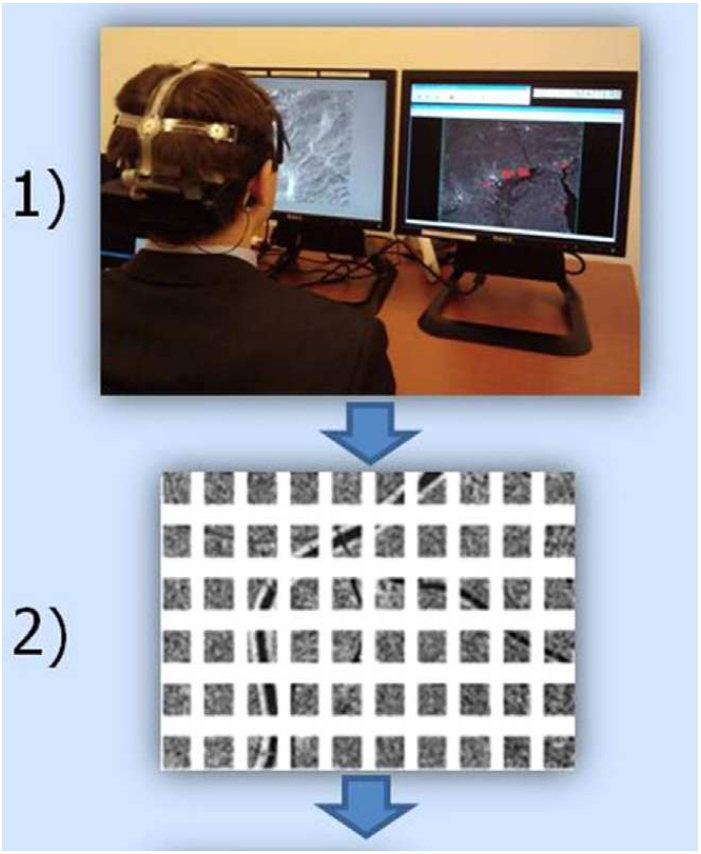
Optogenetics are employed to perform precise, reversible perturbations of brain activity

DARPA BCI projects
restorative encoding memory integration neural device

- Very few have attempted to develop a **cognitive prosthesis**.
- REMIND: development of a BCI system for **memory restoration**.
- Ability to **detect patterns** of **functional brain connectivity** in the hippocampus and prefrontal cortex associated with **successful memory encoding** and **retrieval**.

Studying the spatiotemporal patterns of
hippocampal activity during memory encoding

DARPA BCI projects
Cognitive Technology Threat Warning System



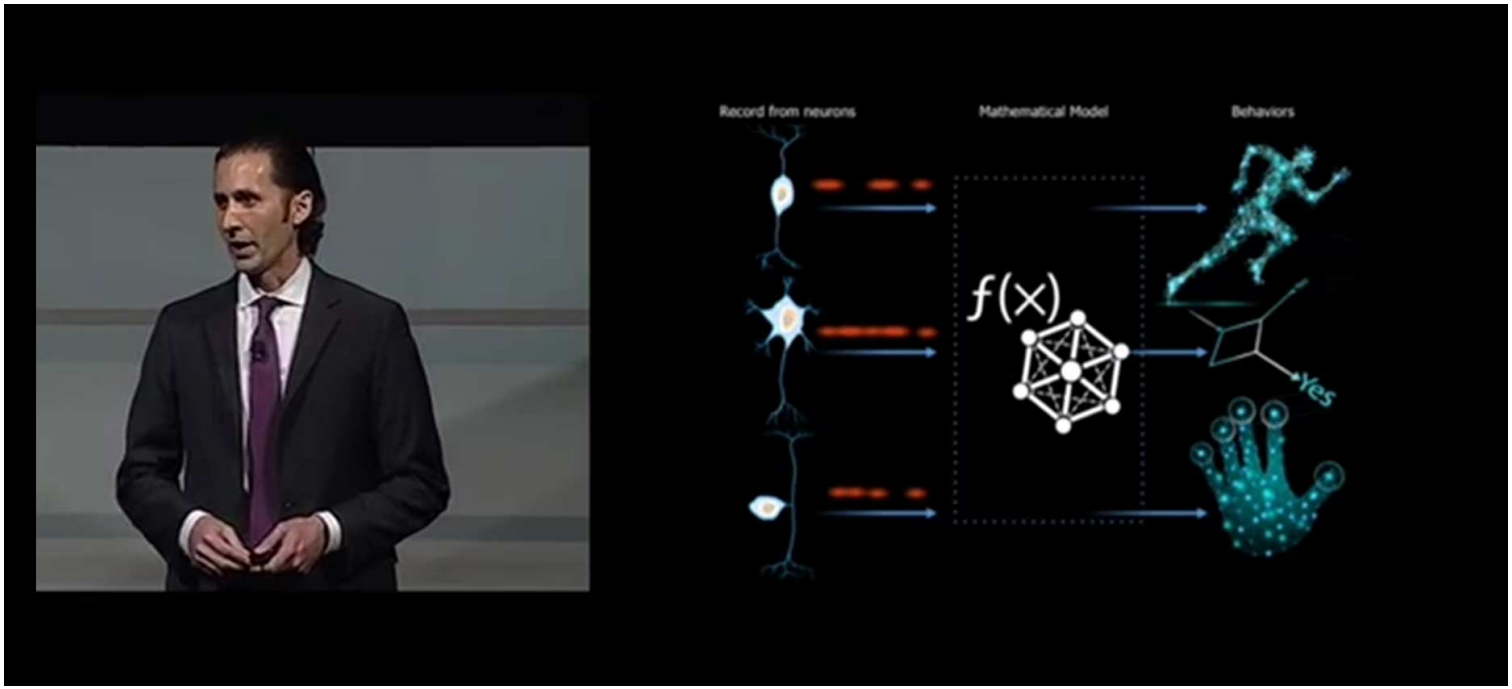
To detect potential threats during real-time surveillance operations

BCI highlights: DARPA

- Brain Research through Advancing Innovative Neuropsychologies (BRAIN) Initiative (April 2013).
- DARPA is currently supporting new research efforts aimed at the development of BCI technologies.
- Restoring human function in human clinical populations with either neuropsychiatric of memory dysfunction.
- **System-based Neurotechnology for Emerging Theraphies (SUBNETS)**: treating complex neuropsychiatric and neurologic disorders.
- **Restoring Active Memory (RAM)**: computational models to characterize the complex organization of memory in the human brain.

DARPA is working with U.S. Food and Drug Administration

BCI highlights: DARPA



DARPA Wait, What? (September/2015)

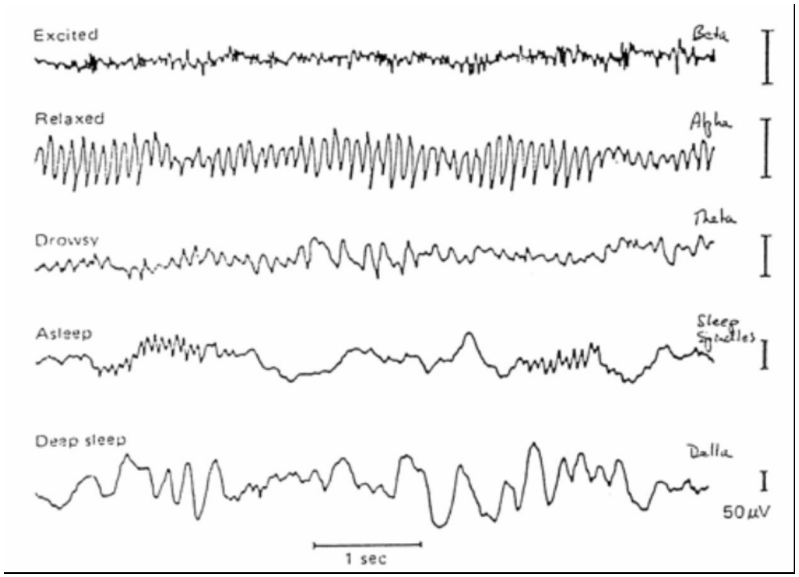
source:

http://edition.cnn.com/2015/09/15/health/prosthetic-hand-senses-touch/index.html

Outline

The research team

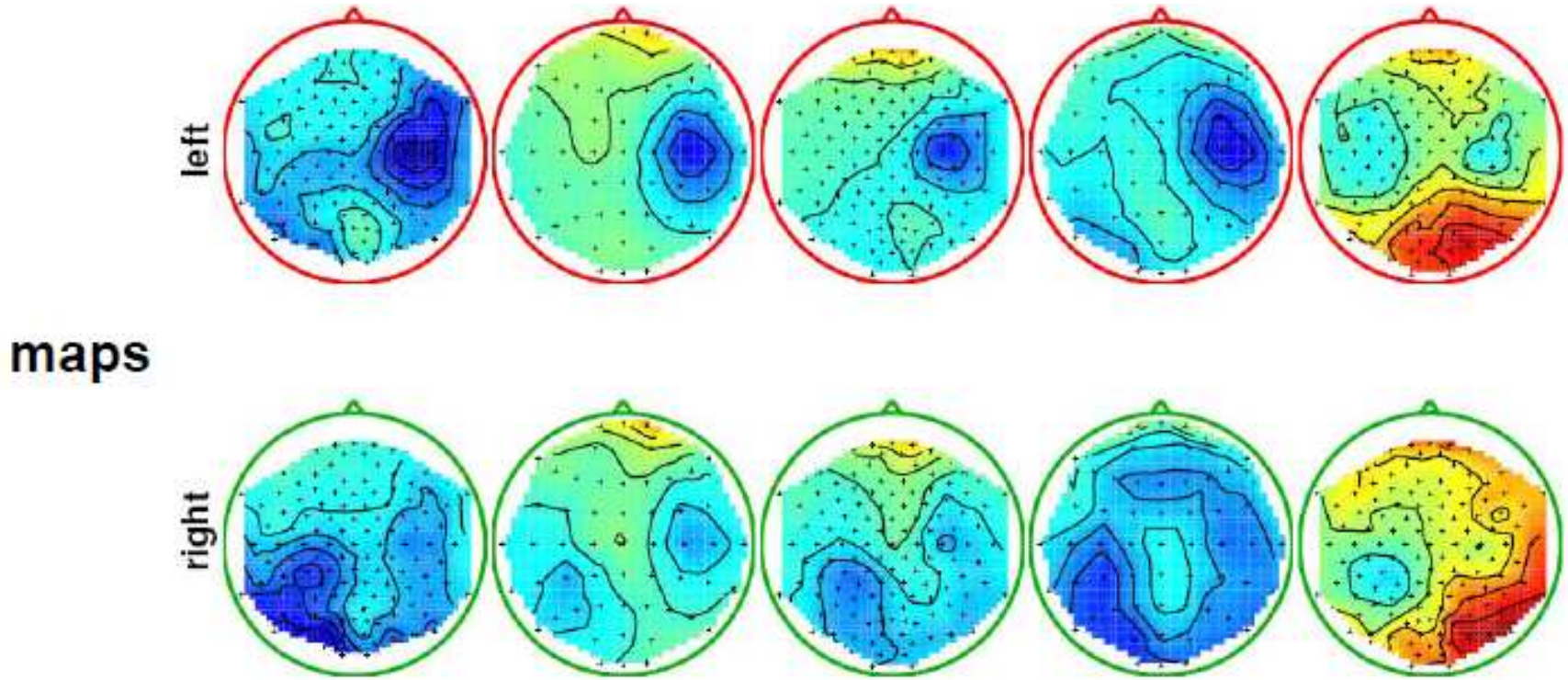
BCI engineering issues



- Noisy signal
- Inter-subject variability

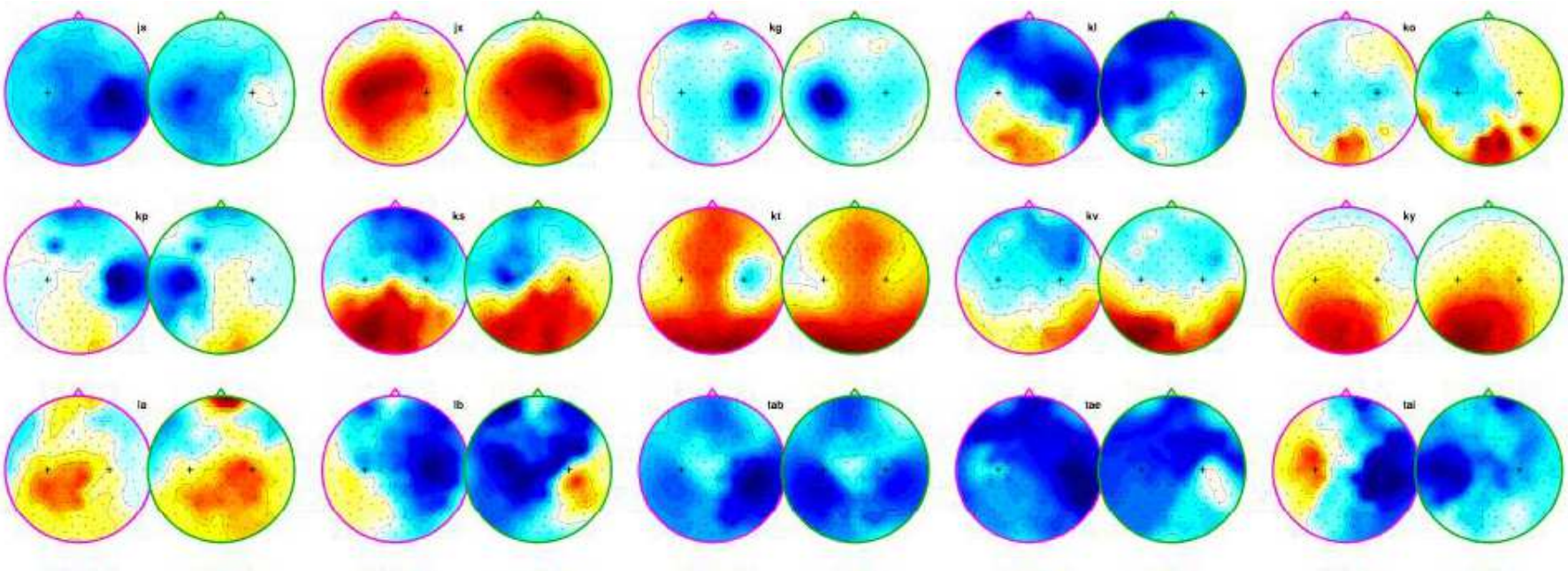
- Non-stationary properties
- **Computational burden issues**
- **Redundant information**

BCI engineering issues



EEG map of a left vs right hand motor imagery task
(One subject on different days)

BCI engineering issues



EEG map of a left vs right hand motor imagery task
(different subjects)

BCI issues

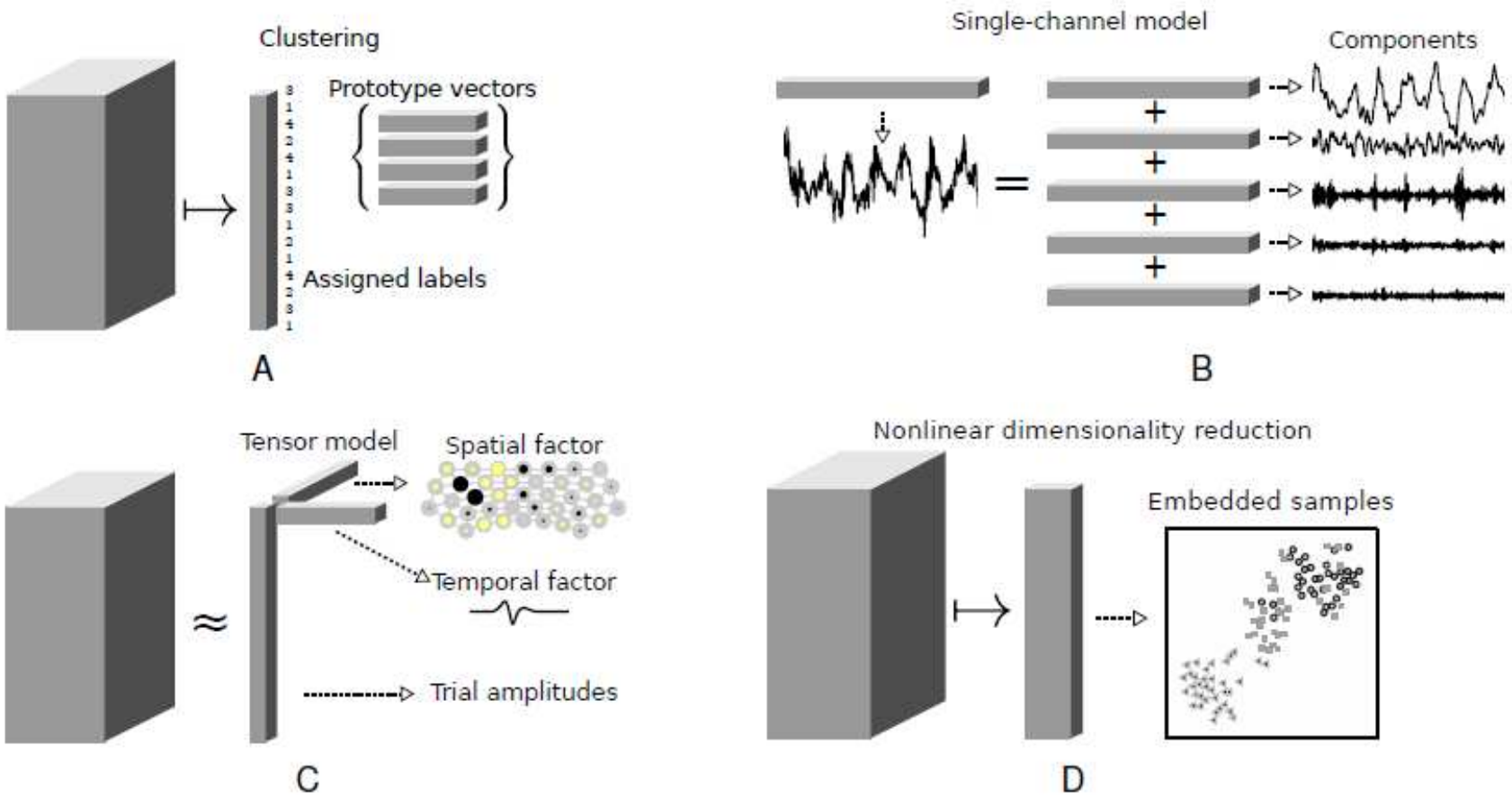
- Estimating the **decoding/encoding models** required by BCIs is difficult on this diverse **high-dimensional** data.
- There are **multiple modalities** by which the signal characteristics differ between conditions.
- **Machine learning** and **signal processing** tools are required to learn an appropriate neural **representation space**.

How can we certainly represent
brain activity to support BCI systems?

BCI and signal processing

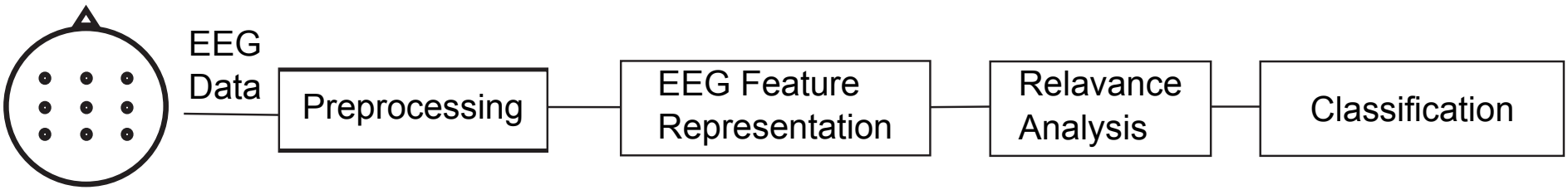
- **Supervised learning scenario**: to find a rule of **association** between pairs (x_n, y_n) of observed **inputs** and corresponding **targets** given an **expert**.
- **Reinforcement learning scenario**: the system **interacts** with the **environment** by performing actions that **feedback** to the system in the form of **rewards** or **punishments**.
- **Unsupervised learning scenario**: the **only available** information is the observed **inputs**. The assumption is the presence of some **data regularities** since there is a process behind their generation.

BCI and signal processing



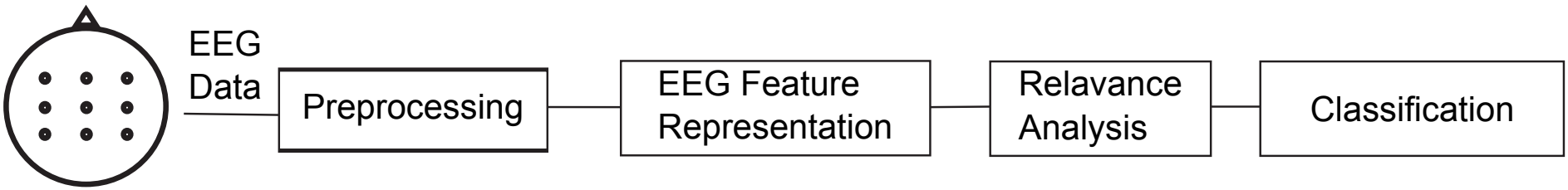
Spatio temporal data representation [Brockmeier, 2014]

BCI and signal processing



A BCI system from a signal processing point of view

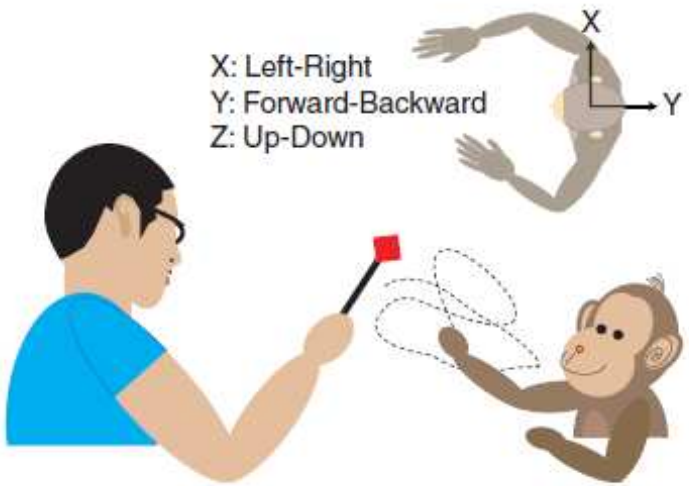
BCI and signal processing



A BCI system from a signal processing point of view

Outline

Neural decoding from ECoG



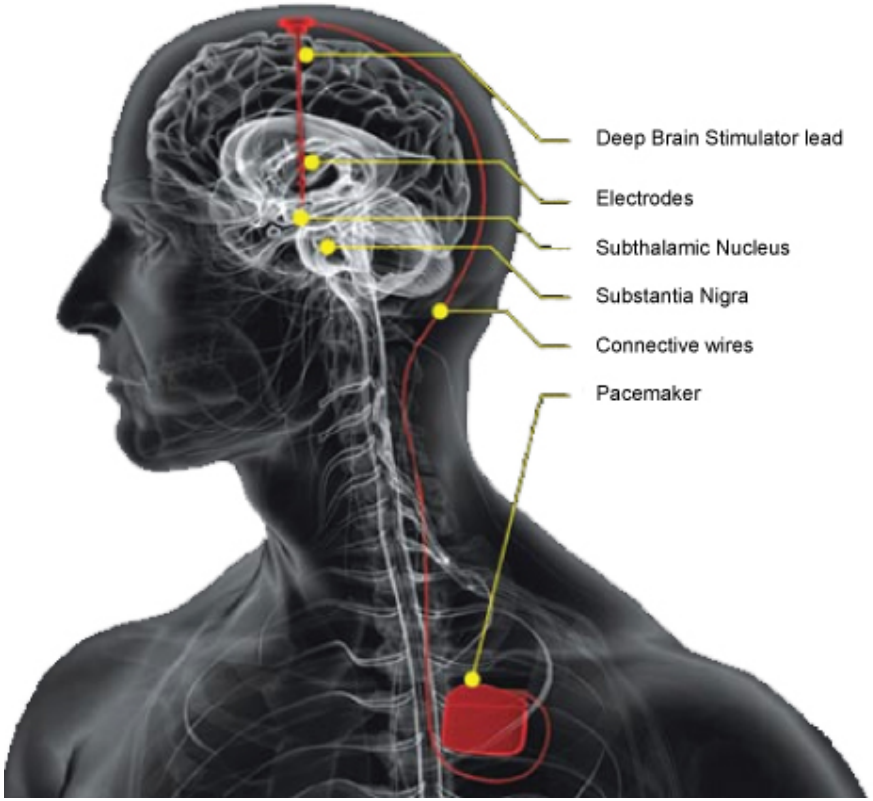
- The goal: to find neural patterns that are related to a given stimulation, e.g., the intention of the movement.
- The issue: Dealing with hidden spatio-temporal relationships.

Neural decoding using the Emotiv device

- The goal: to control a robotic sphere based on a motor imagery classification system.
- The issue: Dealing with hidden spatio-temporal relationships.

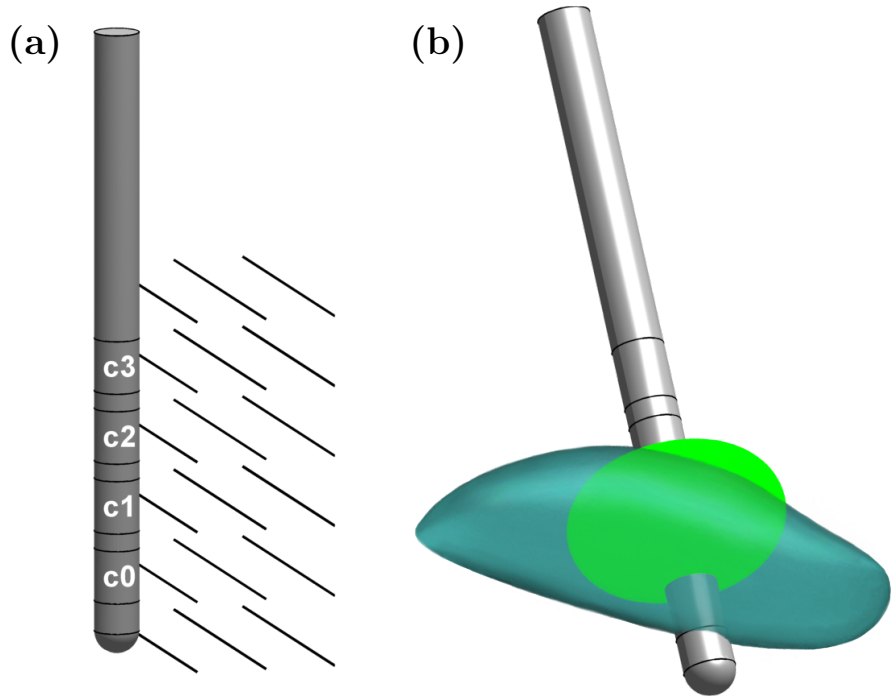
Outline

DBS for Parkinson's disease treatment



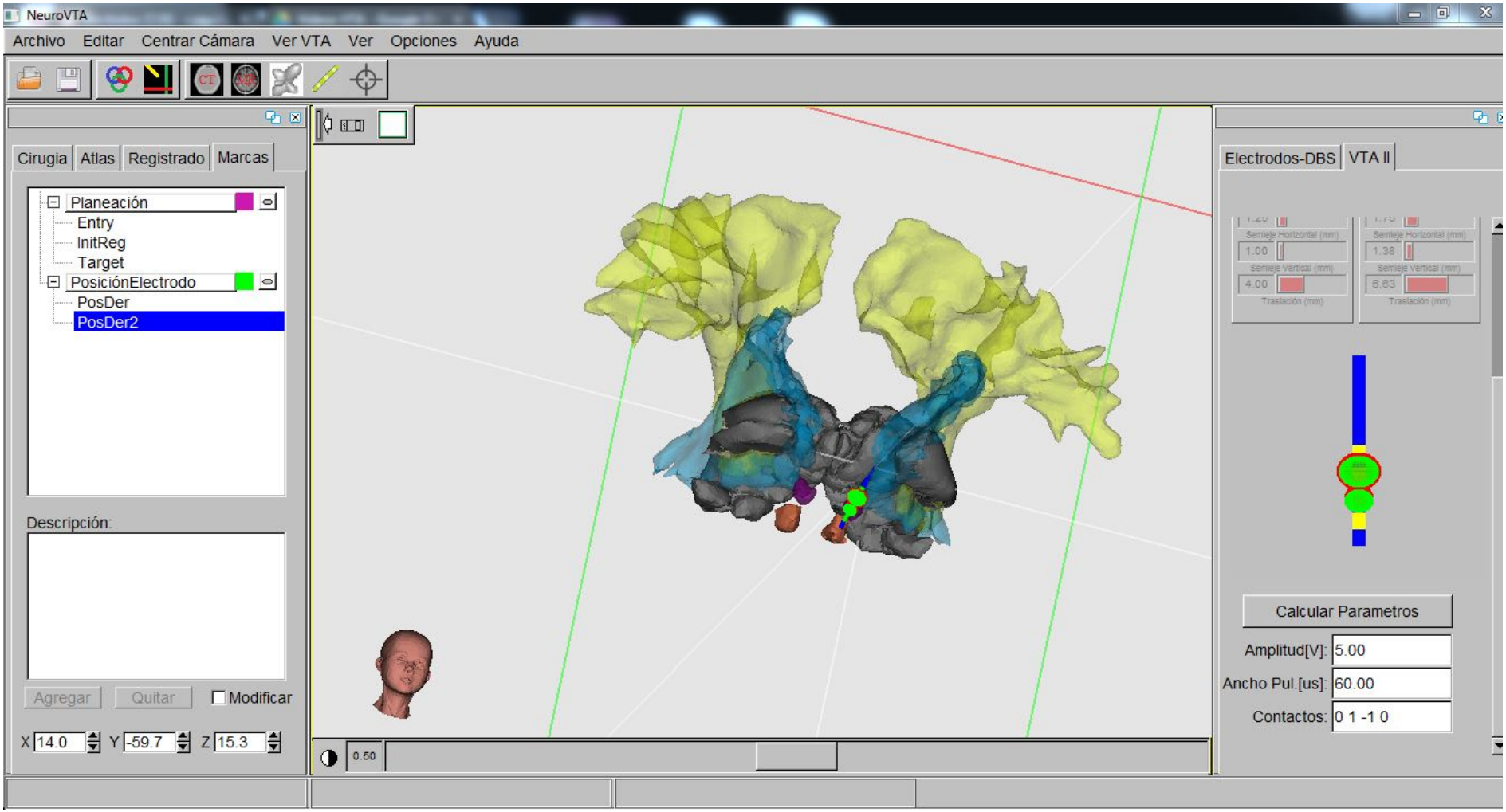
- The goal: to support the Deep Brain Stimulation (DBS) parameter tuning based on signal processing approaches.
- The issue: Dealing with high-dimensional data and ill-possed problems.

DBS for Parkinson's disease treatment



(a) DBS electrode and Volume of Tissue Activated (VTA) representations (Medtronic, model 3389). (b) 3D depiction of a VTA and its spatial interaction with the subthalamic nucleus.

DBS for Parkinson's disease treatment: NeuroVTA



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