# Brain-computer interfaces

Lecture 12

# Outline

- Definition of BCI
- General scheme of BCI
- Classification of BCIs
- Applications of BCI

# Brain-computer interface (BCI)

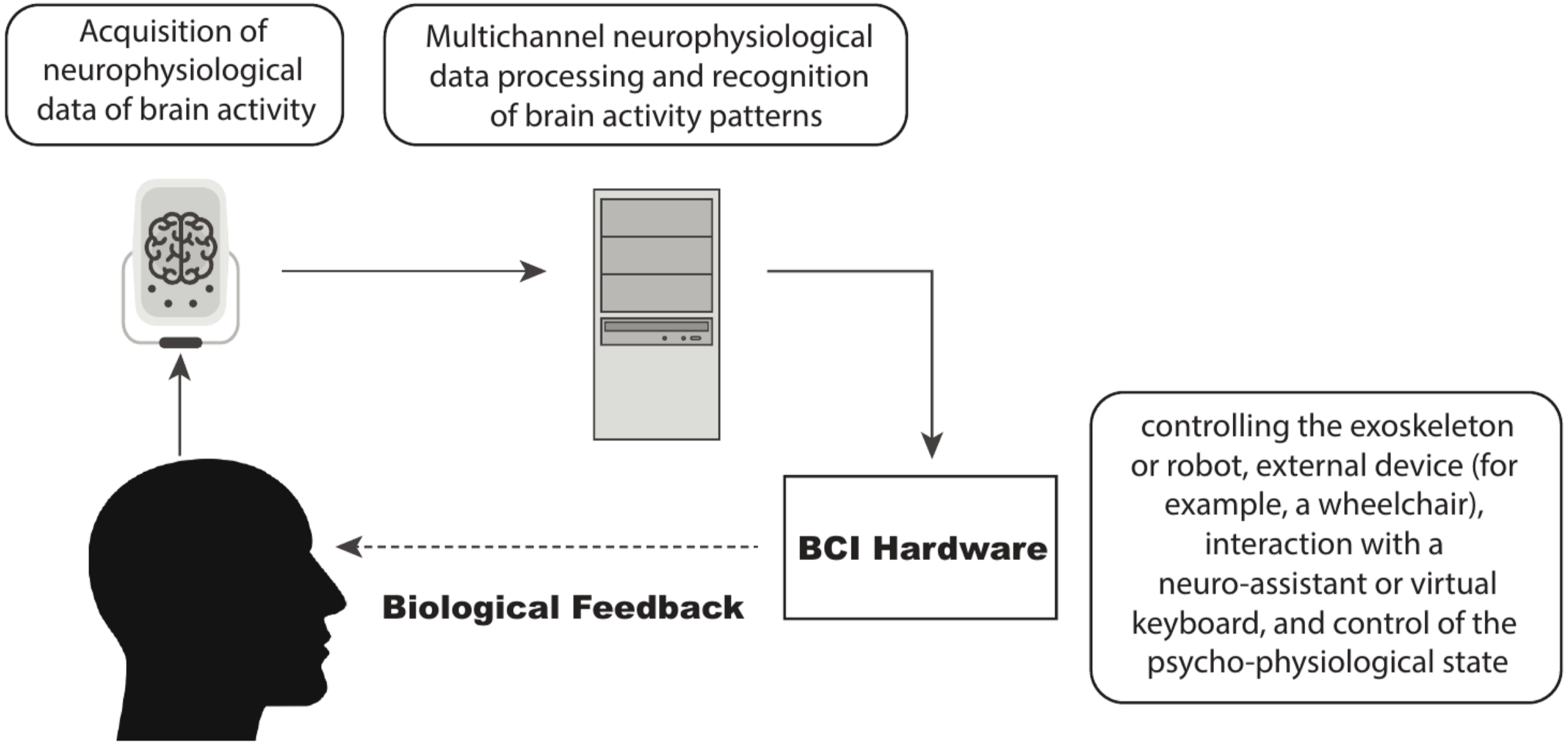
- A brain-computer interface (BCI), or a brain-machine interface (BMI), or simply a neural interface is a hardware-software complex which involves the interconnected functioning of a biological object and a machine, based on a direct connection between computing systems (or other digital intelligent control systems) and the brain.
- Unlike traditional control devices and their interaction with computing systems (keyboards, mice, joysticks, etc.), the BCI registers wave activity in various brain areas and translates these signals into commands for controlling an external digital device without any muscles activity.

# Brain-computer interface (BCI)

The BCIs are of special interest for rehabilitation and improvement of the quality of life of people with disabilities, in particular, for diagnostics and control of brain pathological activity and neurodegenerative diseases;

- rehabilitation of people after brain damage, for example, restoration of motor skills after a stroke;
- analysis and training of human resistance to specific stress effects;
- improvement of self-control and psycho-physiological state quality;
- control of robotic devices, including exoskeletons, to increase human capabilities;
- provide social interactions by allowing social applications to accurately assess and convey a person’s emotions;
- help partially or completely paralyzed people to interact with various external devices (for example, neuro-chat technology, which allows people with disabilities to communicate with themselves and their friends;
- gaming industry;
- having a deeper understanding of brain activity in human and animal neural networks, for example, when mapping brain functions.

# General brain-computer neural interface scheme




Registration of multichannel data on brain activity. The electrical brain activity is most often used, but other types of neuroimaging are also explored.
Intellectual processing of the obtained data and identification of characteristic patterns in real time, transfer of control commands to the interface hardware.
Implementation of biological feedback to monitor the command execution of, training the operator to call necessary mental condition or exposure to it depending on his diagnosed condition.

# First BCI development

- The first neural interfaces were developed in 1973-1977 by a research group of the University of California with the support of the National Science Foundation and the Directorate of Advanced Research Projects of the United States Department of Defense (DARPA).
- In these studies, the author used an analysis of the features of the structure of EEG signals arising from the visual stimuli that appeared during the presentation to the person (the so-called visual evoked potentials).


**J. J. Vidal, Toward direct brain-computer communication, Annu Rev Biophys Bioeng 2 (1) (1973) 157–180.**

**J. J. Vidal, Real-time detection of brain events in EEG, Proc. IEEE 65 (5) (1977) 633–641.**

# Classification of BCIs: control commands based classification

- **Active BCIs** use changes in brain activity that is directly and consciously controlled by the neurointerface operator, regardless of external events, to control the application.
- **Reactive BCIs** detect and classify the brain response (for example, evoked potential) to external stimulation (visual, auditive, tactile, etc.) for the formation of control commands.
- **Passive BCIs** analyse the current brain activity of the user without any target monitoring to obtain information about his/her actual brain state, for example, attention, switching activity, emotional state, etc.

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# Input data processing modality-based classification of BCI

- The synchronous BCI (SBCI) analyzes brain signals only during predefined time intervals, while any brain signal outside the predefined analyzed time window is ignored. Therefore, the operator can formed the command only during specific periods determined by the SBCI system.
- The asynchronous BCI (ABCI) continuously analyses brain signals no matter when the user acts. Therefore, the ABCI represents the user a more natural mode of human-machine interaction than thge SBCI. However, asynchronous BCIs are more computation demanding and complex.

# Advantages and disadvantages of both SBCI and ABCI systems

| BCI type | Advantages | Disadvantages |
|---|---|---|
| SBCI | Simple design and performance evaluation. The user can avoid generating artifacts since they can perform blinks and other eye movements when brain signals are not analysed. | Atypical human-machine interaction occuring in predetermined time intervals. |
| ABCI | No requirement to wait for external cues. Offers a more natural mode of interaction. | More complicated design. More difficult continious processing of brain activity. |

# Invasive and noninvasive BCIs and BMIs

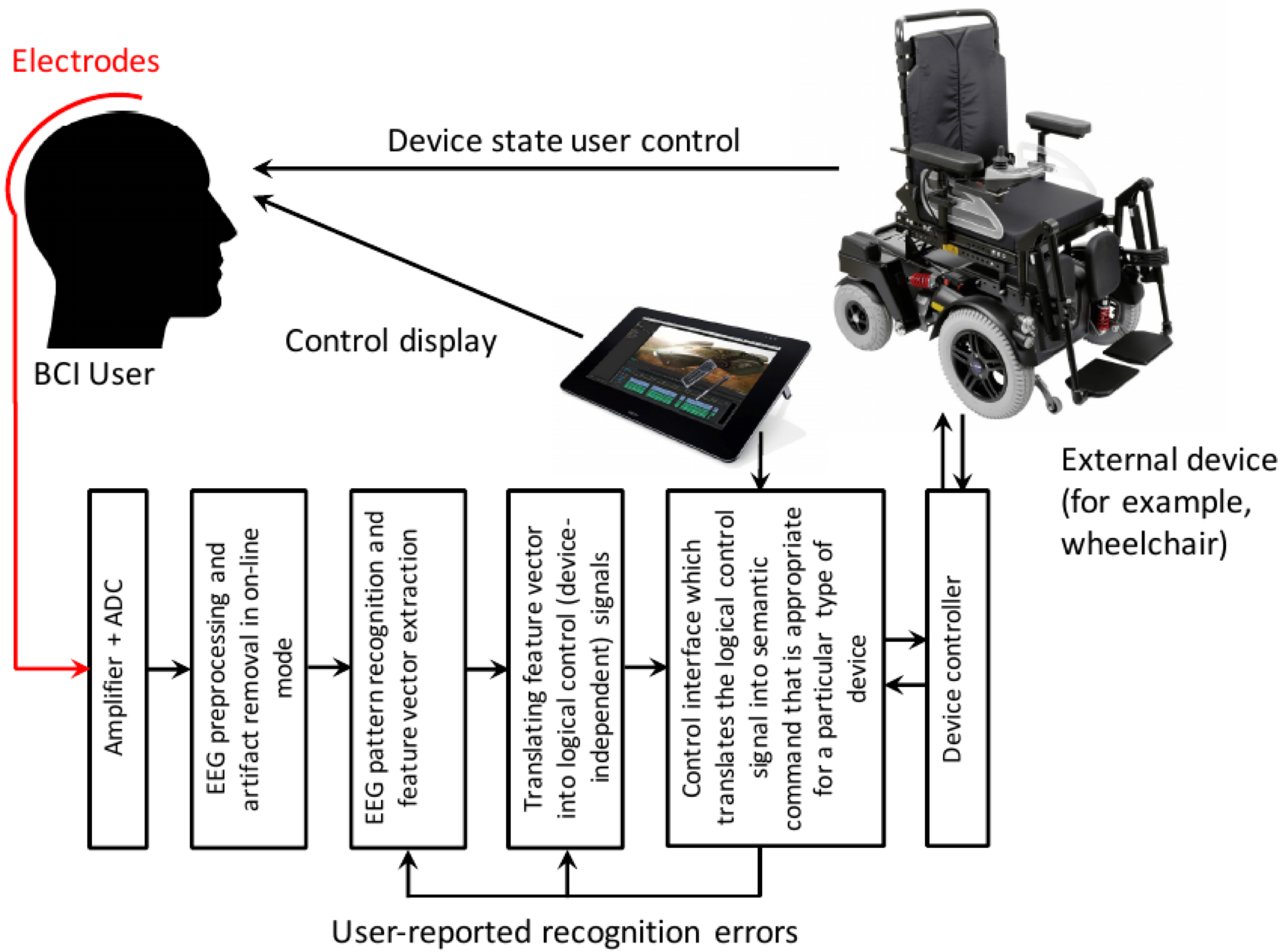
- Non-invasive BCIs are based on recording brain activity from the head surface. This approach has proved useful for helping paralyzed or ``locked in'' patients to develop ways for communication with the external world or to evaluate and control mental states in healthy people.
- In invasive BCIs, registered electrodes are implanted inracranially. This approach provides neural signals of better quality. The invasive BCI approach is based on the EEG recordings from single brain cells (also known as single units) or multiple neurons (also known as multi-units).

# Neuroimaging methods for BCIs

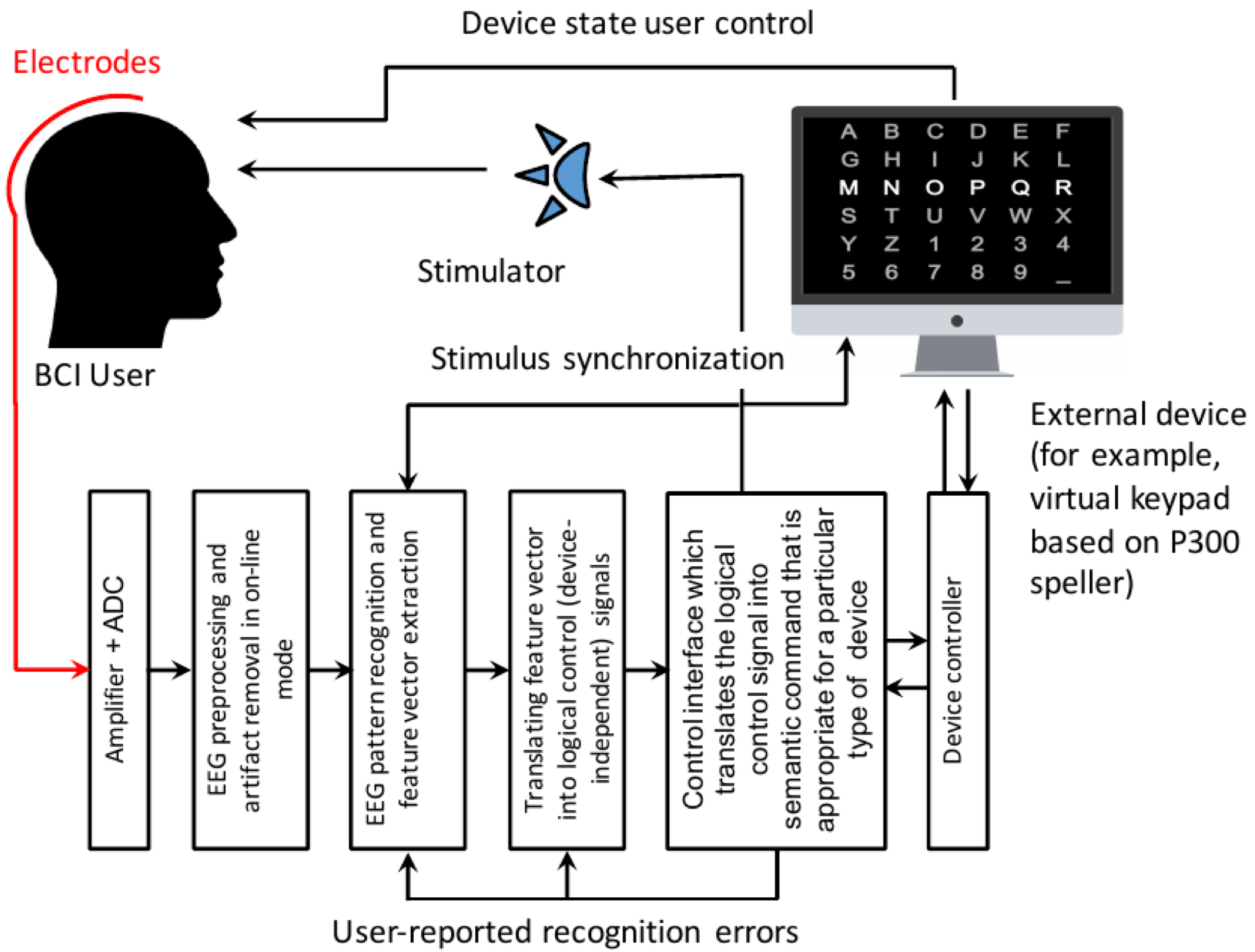
| Method | Value | Measure | Resolution Hz | Resolution mm | Speed bits/min | Portability | Invasivety |
|---|---|---|---|---|---|---|---|
| EEG | EP | Direct | $\sim 100$ | $\sim 10$ | 3–100 | Portable | NO |
| CCR | EP | Direct | $(3\text{–}10)\times 10^3$ | 10–0.5 | 3–35 | Portable | IN |
| ECoG | EP | Direct | $\sim 3 \times 10^3$ | $\sim 1$ | 3–35 | Portable | IN |
| MEG | MF | Direct | $(3\text{–}5)\times 10^3$ | $\sim 5$ | $> 100$ | Stationary | NO |
| fMRI | MB | Indirect | $\sim 1$ | $\sim 1$ | 0.6–1.2 | Stationary | NO |
| NIRS | MB | Indirect | $\sim 1$ | $\sim 5$ | $\sim 4$ | Stationary | NO |

Here EP is an electric potential, MF is a magnetic field, MB is metabolism, IN and NO are invasive and non-invasive techniques.

# Typical active BCI functional model for controlling an external device



# Typical reactive BCI functional model for controlling an external device



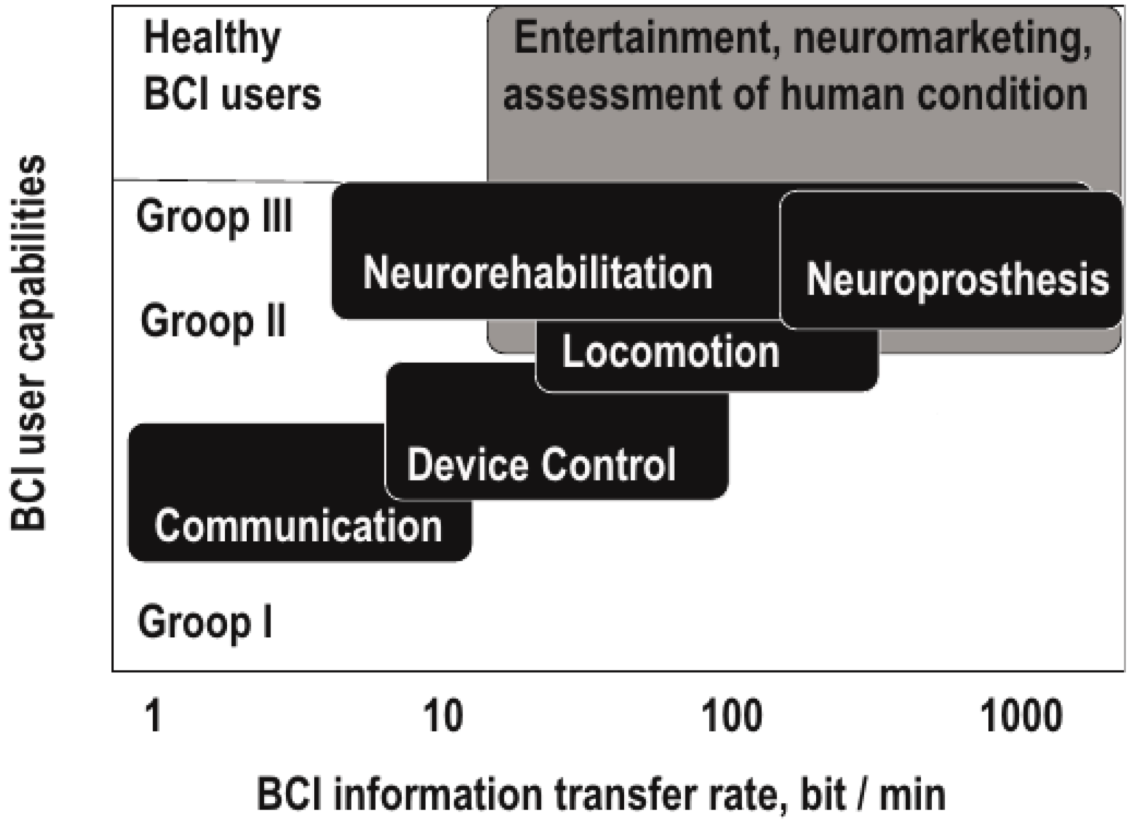
# BCI applications: patients with disabilities

The main target audience of patients with disabilities for the use of active and reactive BCIs can be divided into three groups:

- Group I includes patients with a completely closed consciousness, who have lost all motor control due to the last stage of amyotrophic lateral sclerosis or severe form of cerebral palsy.
- Group II includes patients with almost closed consciousness, who are almost paralyzed, but with residual controlled motor activity, for example, movement or flashing of eyes, twitching of lips, etc.
- Group III potential BCI users includes patients with the remaining neuromuscular control, in particular, with speech disorders, parecs, etc.

# BCI applications

- Possible areas of BCI applications depending on the data transfer rate by BCI and capabilities/restrictions on the operator's health



# Problems of BCIs

- The data transfer rate in the BCI is too low to maintain natural interaction with the technical system or other persons even in the case of a trained operator and a well-tuned BCI.
- When using a BCI, a very large percentage of incorrectly recognized commands by the intelligent control system.
- BCI cannot be used by patients with disabilities alone, without the assistance of classified personnel, because it requires the installation of electrodes and recording equipment before starting work with the BCI.

# Problems of BCIs

- The user often has the ability to disable the BCI using specific brain activity as a BCI input, but usually cannot turn it back on. In neuroscience this problem is called ``Midas touch'' in analogy with the legend about King Midas whose touch transformed any object into gold, that did not allowed him the use of his hands for everyday functions. This problem leads to the inability to distinguish mental states formed during natural brain dynamics from states purposefully formed for interpretation as BCI commands.
- The work with HSC BCI requires high cognitive load for the operator, that can only be achieved in a calm laboratory environment, but not in a real environment. Therefore, the most successful examples of BCI applications were obtained in clinical practice.