Proceedings of the
8th Graz Brain-Computer Interface Conference 2019 DOI: 10.3217/978-3-85125-682-6-58

DEFINING BRAIN-COMPUTER INTERFACES: A HUMAN-COMPUTER INTERACTION PERSPECTIVE

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ABSTRACT: Regardless of the term used to designate them, Brain-Computer Interfaces are "Interfaces" between a user and a computer in the broad sense of the term. This paper aims to discuss how BCIs have been defined in the literature from the day the term was introduced by Jacques Vidal. From a Human-Computer Interaction perspective, we propose a new definition of Brain-Computer Interfaces as "*any artificial system that transforms brain activity into input of a computer process*". As they are interfaces, their definition should not include the finality and objective of the system they are used to interact with. To illustrate this, we compare BCIs with other widely used Human-Computer Interfaces, and draw analogies in their conception and purpose.

INTRODUCTION

In 1973 Jacques Vidal introduced the term Brain-Computer Interface [1]. The "BCI" project as it was imagined back then, was meant to exploit the electrical activity arising from the brain to control a computer program. Even though other terms can be found in the literature to designate BCIs: Brain-Machine Interfaces (BMI), Direct Brain Interfaces (DBI), Direct Neural Interfaces (DNI) or Brain-Interfaces (BI). It is admitted that they all designate the same thing [2]: an interface between a brain and a computer (in the broad sense of the term). This is even noticeable from the fact that most of them share the "I" of "Interface", a term commonly used in Human-Computer Interaction, the field that aims to design, evaluate and implement interactive systems [3].

The main goal of this paper is to stimulate discussion around the terminology of BCIs from a Human-Computer Interaction point of view by discussing the current definitions of BCIs, by highlighting the definition of an "interface" and by setting up an analogy between BCIs and other popular computer interfaces, leading to a new definition of BCI.

CURRENT DEFINITIONS OF BRAIN-COMPUTER INTERFACES

The most widely recognized definition of a BCI was proposed by Wolpaw et al. in 2002: *"A Brain-Computer Interface is a communication system in which messages or commands that an individual sends to the external world do not pass through the brain's normal output pathways of peripheral nerves and muscles"* [4]. The main goal of a BCI would be then, to allow users who may be suffering from "locked in" syndrome or "paralysis" to communicate and to express their wishes to caregivers, or to operate word processing programs and neuroprostheses. The very core idea of a BCI would thus be to provide the brain with *"a new, non-muscular communication and control channel for conveying messages and commands to the external world"*. This brings up a core element of a BCI which is the "non-muscular" nature. A BCI derives its input solely from the brain activity.

A few years later, Blankertz stated that a BCI is *"a new augmented communication system that translates human intentions reflected by suitable brain signals, into a control signal for an output device such as a computer application or a neuroprosthesis"* [5]. An interesting feature of this definition is the concept of translation. In order to interact using a BCI, the brain activity has to be transformed into commands or messages.

According to Daly and Wolpaw [6], a BCI system *"enables a new real-time interaction between the user and the outside world"* specifying that the signals extracted from brain activity *"are translated into an output"* from which the user receives feedback that affects his brain activity. This definition highlights the real-time component of a BCI system and introduces the notion of closed-loop between the user and the system through the feedback.

Aggregating the previously mentioned features, Grainmann et al. [7] stated 4 criteria under which a system can be called a BCI: (1) A BCI system has to acquire its inputs *directly* from the brain activity; (2) The signal has to be processed and translated in *real-time*; (3) The user must obtain *feedback* from his activity; (4) The user has to send *intentional* commands

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to the system. The last criterion though, has been qualified by a newer classification of BCIs proposed by Zander and Kothe [8] who distinguish between *active, reactive* and *passive* BCIs depending on the endogenous and intentional nature of the interaction. Today, passive BCIs should also be considered as BCIs.

All these definitions across time have helped better understand and better design Brain-Computer Interfaces. They are remarkably complementary and perfectly describe what most of the BCI systems are able to achieve today, in terms of communication and control. However, most of these definitions go beyond what can etymologically fall into the definition of an interface.

From an HCI perspective, considering the usage of the term “interface”, strictly speaking, the term Brain-Computer Interface should only be applied to describe the intermediary hardware and software components between the brain and the interactive system.

A NEW DEFINITION OF A BRAIN-COMPUTER INTERFACE

In the Oxford dictionary, the word “interface” defines “*A point where two systems, subjects, organizations, etc. meet and interact*” [9]. In the context of computing, it defines “*A device or program enabling a user to communicate with a computer*”. From both of these definitions, it clearly appears that the notion of interface only makes sense when considering the items it helps to bridge. In HCI, these two items are the “user” and the “interactive system”.

A system is said to be interactive if it depends on unpredictable inputs incoming from an external environment that it does not control [10]. In HCI, the unpredictable inputs are the user commands.

In this context, an interface is the set of hardware and software means by which the user communicates with the interactive system. The interface comprises the input device (the hardware), the algorithms and methods to process the outcomes of the input device, and the presentation mechanisms to render the feedback. The final objective of the system though, does not belong in the boundaries of the interface. A computer mouse for example, is made of hardware parts, comprising the plastic box, the motion sensor and the microcontroller, for measuring the user movements. It also requires a transfer function for translating these movements into the motion of a pointer displayed on screen, and the presentation of graphical elements (i.e. buttons) so that the user can designate elements to interact with.

We believe that any BCI comprises the same set of components as any user-computer interface. Hence, arising from an HCI perspective, we propose to define a Brain-Computer Interface as:

“*any artificial system that transforms brain activity into input of a computer process”.*

COMPARATIVE STUDY: A COMPUTER MOUSE VS. AN SSVEP-BASED BCI

Brain-Computer Interfaces have a lot in common with other Human-Computer Interfaces. Both aim to allow the communication between a user and a computer system. Moreover, even in terms of design and components, BCIs and HCI interfaces often share the same high-level architecture.

In this section, in order to explain our point of view, we choose to illustrate the similarities between a Steady-State Visual Evoked Potential (SSVEP) based BCI, based on EEG, and a computer mouse. SSVEP is a reactive paradigm based on the property that the brain, when the subject is focused on a periodic visual stimuli of frequency *f*, reacts with an increase in its activity at the same frequency *f*. In other words, it means it is possible to determine the frequency of periodic stimulation the user is focused on. Interested readers may refer to [11] for more details.

The choice of the SSVEP and a computer mouse is arbitrary, and the same analogy could be drawn with other instances. Figure 1 illustrates the different components of this analogy.

Hardware components: The first thing that comes to users’ mind when they hear “computer mouse”, is the plastic-made body. Similarly, the first thing that comes to mind when evoking a BCI is the EEG cap itself with its electrodes. In fact, both of them correspond to the entry point of the interface for the user. The second component of the mouse is usually a digital camera, the microcontroller and the LED lens embedded in the body which are responsible of acquiring the user’s hand movements. In the case of an EEG BCI, it is the amplifier that provides one time-dependent signal per measured electrode.

Software components: In both of the computer mouse and the BCI, the software components hold an important part. In the mouse, the direction, amplitude and speed of the hand movement are translated into new coordinates for the cursor on the screen using a transfer function. These movements can typically be predicted by Fitts’ law [12]. In a BCI, the amplified EEG signal is processed and classified into a mental state. Depending on the mental state, and depending of the position of the cursor when clicking, a particular command is determined from the interface and sent to the interactive system.

Presentation: In the cases of the mouse and an SSVEP BCI, a graphical presentation is primordial. For the SSVEP BCI, it is essential to have external stimuli under the form of flickering targets, in order to infer different commands from the BCI. This is what makes SSVEP a reactive paradigm. For the mouse, on the other hand, it is necessary to present buttons or specific areas on the screen so that the user knows where to click. In the same way as clicking on different buttons generate different commands, focusing on targets flickering at different frequencies will generate different commands.

This analogy between a mouse and a SSVEP BCI do

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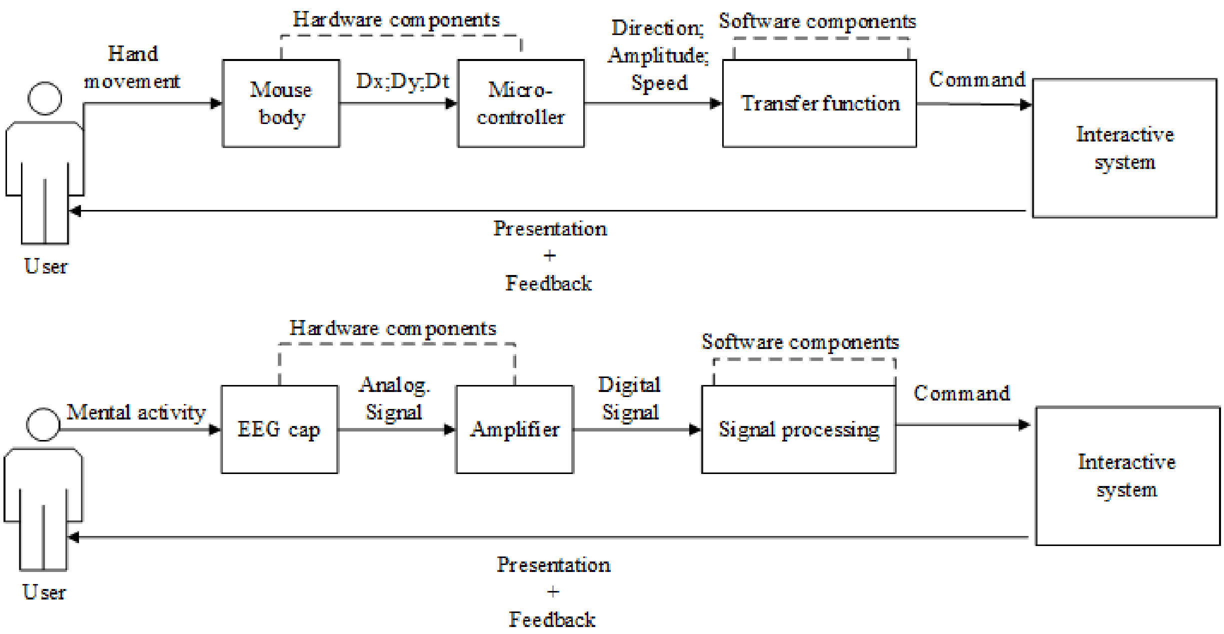

Figure 1: Illustration of the components comprised in a user interface. (Top) A Brain-Computer Interface comprises an acquisition equipment, a signal amplifier and all the methods used to transform the signal into a computer input. (Bottom) A computer mouse is made of a hardware body, a microcontroller and a transfer function.

apply to other reactive paradigms. Yet, it is possible to draw the same kind of comparison for active or passive BCIs. In the case of Motor Imagery for instance, we can easily make an analogy with a joystick or a game controller. When the subject imagines left or right-hand movement, the appropriate command is sent to the interactive system, without the need for a graphical presentation, even though a feedback mechanism can help.

For passive BCIs, it is possible to draw a comparison with proactive and transparent interfaces. A good example of this would be a smart-home interface, where the user's behaviors and locations are transparently monitored to infer commands to send to the smart-home. Adapting a system to the user's mental state can somehow be seen as automatically turning on the light when the user moves into the room.

These comparisons and analogies have to be seen as what they are meant to be: illustrative examples. They are not intended to be exhaustive nor universal truth, but they serve to illustrate that a Brain-Computer Interface can fundamentally be seen as a Human-Computer Interface.

DISCUSSION

There have been several definitions of Brain-Computer Interfaces since Jacques Vidal introduced the name. Today, research and innovation in the field of BCIs is very transversal. Neuroscientists, computer-scientists, medical doctors and engineers have different perspectives on what Brain-Computer Interfaces are.

The definition we proposed, present the advantage of being very inclusive because it does not comprise the finality of the interactive system.

Instead, we consider "*any*" system, that unlike muscles is "*artificial*" and falls in the proposed definition as a BCI. The purpose of this system is to "*transform*" the brain activity into "*inputs*" that a "*computer process*" can exploit.

A similar reflection has been conducted by Jeunet et al. [13] when comparing Neurofeedback and Motor Imagery. They highlighted that both Neurofeedback (NF) and MI-BCI users have to learn how to regulate their neurophysiological activity, sometimes with similar features, through given feedback but the final objective is different. While MI-BCI consists in producing a specific EEG pattern to send a command, the goal of NF is to learn how to generate the specific pattern.

If one wants to designate the whole interaction between a user and an interactive system using a BCI to achieve a particular role, one should use the term Brain-Computer Interaction.

With our new definition of Brain-Computer Interfaces (BCI), any artificial system that involves the exploitation of brain signal, can be considered as using a BCI, instead of being the BCI itself.

CONCLUSION

In this discussion paper, our goal was to explore the different definitions of Brain-Computer Interfaces. All these definitions are very complementary, reflect the transversality of the field, and illustrate what it is possible to achieve with BCIs today. In an attempt to aggregate these definitions, in order to be as inclusive of new and incoming types of BCIs as possible, we proposed a new definition motivated by the etymology of the term, and with our perspective from the Human-

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Computer Interaction domain. We illustrated and grounded our point of view through an analogy between BCIs and more widely used interfaces.
We believe that this new definition could support the future discussion about what BCIs are, and that it could constitute a first step towards the design of Brain-Computer Interfaces as interaction medias.

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