The following article represents the first of a series of reports on Brain-Computer Interfaces. It presents an overview of the field, its technologies and methods, and also its main goals. A subsequent report will present the main achievements of BCI research during the past two decades, followed by a report on novel BCI-based approaches. The final report will contain an overview of freely available tools and methods needed for building up your own BCI laboratory.

**BCI in a nutshell**

A Brain-Computer Interface (BCI) is a direct link between a human brain and a technical system. It detects patterns in brain activity and translates them into input commands given to the machine. Usually, brain activity is recorded using an EEG system and is interpreted by a conventional personal computer using machine learning and signal processing techniques. The initial, principal goal of BCI-based applications has been to provide communication and control channels for users who have lost their ability to communicate naturally. These are mainly patients suffering from amyotrophic lateral sclerosis (ALS) or tetraplegia.

From the perspective of Human-Machine Systems (the science of interaction between humans and machines), a BCI defines a new input modality for the active or passive transmission of commands. Active commands are intentional and focused, like a mouse click, while passive commands are not the result of deliberate intentions. A passive command can, for example, be derived from the brain’s reaction to the perception of an error or other aspects of cognitive user state.

Figure 1 depicts how a BCI could be implemented in the context of a human-machine system feedback loop.

**Goals of BCI research**

Attaining the primary goal of providing a channel for communication and control that relies on no other human bodily activity besides that of the brain requires the attainment of several sub-goals.

**Optimizing signal acquisition**

The first step in Brain-Computer interfacing is to acquire information on brain activity. As a BCI is intended for long-term use a proper sensor is needed that is quick and easy to apply, is...
as unobtrusive as possible, provides reliable information on brain activity, and operates without harming the user. EEG partially fulfills these criteria, but there is some scope for optimization. The use of gel for impedance reduction is time consuming, limits the length of time that a BCI can continuously be used, and means that the user’s hair needs to be washed afterwards. Also, as the gel is usually abrasive, uncomfortable skin irritations can develop in long term use. Sensor technology therefore needs to be improved. First dry electrodes are presently being developed. These could provide a quality of data that is similar to that of the EEG systems currently in common use, but without the need for any liquids.

**Defining features in EEG**

Another important BCI research issue involves the identification of distinctive EEG features that can provide useful information on the user’s current cognitive state. The term ‘Features in EEG’ refers to characteristic task- or state-related EEG patterns that can be used to infer information on the current state of the subject’s brain. One major criterion for the usefulness of such features is that the user must be able to generate the features easily. But, as EEG is no unique mapping of brain activity (mostly because of volume conduction and the reduction of the signal to two spatial dimensions) it is vital to minimize the likelihood of interference from features that may be generated by other cognitive processes and projected in a similar manner. Last but not least, the selected features should be easy to detect using automated methods. Typically, it is important to ensure a good signal-to-noise ratio; this can be achieved with signals that display low variance and strong coherence across trials, as well as high amplitudes in the time or frequency dimensions. In this respect, BCI research benefits strongly from previous research done in neuroscience, providing a lot of information on features possibly suitable for BCI applications. Detailed examples will be included in the second report, which will focus on BCI research.

**Detecting BCI-features**

Another main task for BCI research is the development of efficient algorithms for translating brain activity into input commands. From an abstract perspective, these algorithms select and transform those portions of EEG data that best reflect a previously-selected brain activity pattern. This results in BCI features that do not necessarily retain the structure of EEG data and are consequently more abstract than the standard features. This is usually done in a three-step process. EEG produces a lot of data that conveys no information about the process being investigated and must be filtered out. Accordingly, a first step is to apply restrictive filters – that are implemented retaining causality, in contrast to the signal processing typically used in EEG analyses. This restricts the temporal, spatial and oscillatory bandwidth of the EEG recording. Subsequently, features will be extracted based on knowledge derived from the neurosciences. In this step, particular components of the data will be selected, combined and attenuated by further processing. The final step is to calibrate a classification algorithm based on prototypical features that are usually generated in a separate training session. The resulting algorithm is used in the final application to derive information on the cognitive user state from the EEG. It is therefore highly important that BCI research has proper tools at its disposal that enable the optimal selection of features.

**Ingredients of BCI research**

Research in the BCI field is usually highly interdisciplinary, and has its foundation chiefly in the neurosciences, psychology, mathematics and computer science. However, in recent years, as more BCIs are being incorporated in non-laboratory applications, BCI research has also been influenced by the fields of human factors, cognitive science, engineering and human-computer interaction (HCI). The neurosciences supply valuable information regarding the structure and functionality of the human brain. Proper analysis of the results and the setting-up of experimental designs in which the factor of investigation could be modulated while other factors are controlled, as well as the drawing of accurate inferences from a given set of results, is contributed by the domains of psychology and cognitive science. Mathematics and Computer Science usually are consulted for building up a system for automating predefined steps of inference on EEG data. The knowledge and techniques derived from the fields of human factors, engineering and HCI are invaluable for setting up a usable and effective application that is based on BCI input. The systems constructed must make efficient use of the limited bandwidth available in a BCI system. This can be done by optimizing the interface design, incorporating as much automation as possible and including information on the environmental, user-related and technical state of the system being used.

**Possible areas of application**

The initial, principal purpose of BCI systems is to provide a mechanism for communication and control that can be used...
by severely disabled people. However, as the reliability and usability of BCI systems has improved during the past decade, their applicability and appeal for other applications has also grown. With the introduction of passive and hybrid BCI systems, this technology could also be of interest to users in a normal state of health. In particular, users in specialized working environments, such as astronauts, surgeons and people interacting in augmented environments, might benefit from being able to use additional input mechanisms. This will be discussed in more detail in the next Press Release issue.