Preface

What Is BCI2000?

BCI2000 is a general-purpose software platform for brain–computer interface (BCI) research. It can also be used for a wide variety of data acquisition, stimulus presentation, and brain monitoring applications. BCI2000 has been in development since 2000 in a project led by the Brain–Computer Interface R&D Program at the Wadsworth Center of the New York State Department of Health in Albany, New York, USA, with substantial contributions by the Institute of Medical Psychology and Behavioral Neurobiology at the University of Tübingen, Germany. In addition, many laboratories around the world, most notably the BrainLab at Georgia State University in Atlanta, Georgia, and Fondazione Santa Lucia in Rome, Italy, have also played an important role in the project's development.

Mission

The mission of the BCI2000 project is to facilitate research and the development of applications in all areas that depend on real-time acquisition, processing, and feedback of biosignals.

Vision

Our vision is that BCI2000 will become a widely used software tool for diverse areas of research and development.

History

In the late 1990s, Dr. Jonathan Wolpaw, a BCI pioneer at the Wadsworth Center, recognized the need for a software platform that would facilitate the implementation of any BCI design. This need was supported by Dr. Niels Birbaumer, another BCI pioneer from the University of Tübingen in Germany. Their joint interest resulted in a meeting that lasted for several days and took place in Tübingen in late 1999. It was attended by Gerwin Schalk and Dennis McFarland from the Wadsworth Center, and Thilo Hinterberger from the University of Tübingen. This meeting resulted in a first set of general system specifications. Because these system specifications were focused on technical flexibility but also practicality, they have not changed since then and there has not been a need to change them.

The next year and a half were characterized by the implementation of the first generation of the BCI2000 system, primarily by Gerwin Schalk and Dennis McFarland at the Wadsworth Center. These efforts culminated in the first successful BCI2000-based experiment in July 2001. The data files generated in that first set of experiments can still be interpreted today with the tools provided by BCI2000. Just like all other BCI2000 data files, these early data sets contained a full record of the parameterization of the experiments, and of the time course of important events such as the timing of stimulus presentation. Thus, it is possible to completely reconstruct all important details of experiments that were conducted many years ago.

During 2002, Jürgen Mellinger at the University of Tübingen joined the BCI2000 project and immediately began to improve the initial system implementation. The project also received initial exposure during the 2nd International BCI Meeting in Rensselaerville, NY, which was organized by the Wadsworth Center. This exposure resulted in the extension of the BCI2000 system to support a P300-based spelling device modeled after the methodology described in [7], and in the first adoption of the BCI2000 system by other research groups (e.g., Dr. Emanuel Donchin, University of South Florida; Dr. Scott Makeig, Swartz Center for Computational Neuroscience, La Jolla; Dr. Melody Moore-Jackson, Georgia State BrainLab). During 2004, Adam Wilson, then a graduate student at the University of Wisconsin at Madison and who has since worked as a postdoctoral associate at the Wadsworth Center, began to use BCI2000 and to contribute to the project.

Since the early years, the design and development of the BCI2000 platform have been subject to two contrasting forces that needed to be appropriately managed. These forces were the desire to develop a robust general-purpose BCI system (i.e., a long-term goal) on the one hand, and the necessity to support many different BCI experiments in Albany and Tübingen (i.e., short-term goals) on the other hand. In 2005, the continually improving BCI2000 platform and the initial success in the system's dissemination provided the basis for an NIH grant proposal dedicated to the further development and maintenance of the BCI2000 platform. (Initial BCI2000 development had been sponsored by an NIH Bioengineering Research Partnership (BRP) grant to Dr. Jonathan Wolpaw.) In 2006, this grant application was awarded for an initial four-year period by the National Institute of Biomedical Imaging and BioEngineering (NIBIB) of the NIH. This dedicated funding allowed the project team to focus entirely on the needs of the BCI research community rather than simply the needs of individual research projects. The resulting work culminated in the release of BCI2000 V2.0 in early 2008. This version represented the largest single advance since the project's inception. In V2.0, we consolidated and expanded the existing BCI2000 platform and associated development and maintenance processes to achieve a consistent set of quality core components, comprehensive and up-to-date documentation for users and software engineers, and testing and release management procedures. Since the release of version 2.0, the adoption of the BCI2000 platform has accelerated further. Many scientists and engineers are now requesting BCI2000 for purposes other than BCI research.

As we are writing this book, BCI2000 V3.0 is about to be released. This system increases performance (particularly on machines with multiple processor cores), supports VisualStudio and MinGW in addition to Borland/CodeGear compilers, and further modularizes BCI2000 components.

Impact to Date

BCI2000 has already had a substantial impact on BCI and related research. As of December 2009, BCI2000 has been acquired by nearly 500 laboratories around the world. The original article that described the BCI2000 system [19] has been cited more than 200 times, and was recently awarded a Best Paper Award of 2004 by *IEEE Transactions on Biomedical Engineering*. Furthermore, a review of the literature revealed that BCI2000 has been used in studies reported in more than 120 peer-reviewed publications. These publications include some of the most impressive BCI demonstrations and applications reported to date. E.g.: the first online brain–computer interfaces using magnetoencephalographic (MEG) signals [15] or electrocorticographic (ECoG) signals [8, 11, 12, 23]; the first multi-dimensional BCI using ECoG signals [22]; the first applications of BCI technology toward restoration of function in patients with chronic stroke [3, 24]; the use of BCI techniques to control assistive technologies [6]; the first real-time BCI use of high-resolution EEG techniques [5]; demonstrations that non-invasive BCI systems can support multi-dimensional cursor movements without [25, 26] and with [14] selection capabilities; control of a humanoid robot by a noninvasive BCI [2]; and the first demonstration that people severely paralyzed by amyotrophic lateral sclerosis (ALS) can operate a sensorimotor rhythm-based BCI [10]. BCI2000 is also supporting the only existing long-term in-home application of BCI technology for people who are severely disabled. In these ongoing studies by Jonathan Wolpaw and Theresa Vaughan at the Wadsworth Center, BCI2000-based systems are being placed in the homes of severely disabled people. For the past several years, these individuals have been using the BCI for word processing, email, environmental control, and daily communication with family and friends.

Many studies have used BCI2000 in fields related to BCI research. This includes the first large-scale motor mapping studies using ECoG signals [13, 17]; real-time mapping of cortical function using ECoG [16, 21]; the optimization of BCI signal processing routines [4, 18, 27]; evaluation of steady-state visual evoked potentials (SSVEP) for BCI purposes [1]; and the demonstration that two-dimensional hand movements and finger movements can be decoded from ECoG signals ([20] and [9], respectively). Facilitated by the easy exchange of data and experimental paradigms that BCI2000 enables, a number of these studies were performed as collaborations among several geographically widespread laboratories. To our knowledge, there have been no comparable large-scale collaborative BCI studies that have not used BCI2000.

Furthermore, BCI2000 has also been: used in demonstrations on national television including NBC, CBS, and CNN; referenced several hundred times in journal articles, media articles, and personal blogs; used or cited in dozens of Masters Theses or Doctoral Dissertations; listed as a significant qualification in curricula vitae; and even mentioned as desirable experience in job postings. The widespread and continually growing success of the BCI2000 platform is strong evidence for its utility.

In summary, BCI2000 is promoting and facilitating the evolution of BCI research and development from isolated laboratory demonstrations into clinically relevant BCI systems and applications useful to people with severe disabilities. As indicated by the above descriptions of its utility for many different aspects of BCI research, by its wide dissemination, and by its prominence in the scientific literature, BCI2000 is fast becoming, or perhaps has already become, the standard software platform for BCI research.

Dissemination

The BCI2000 software is available free of charge for research and educational purposes at http://www.bci2000.org. This web site contains comprehensive project-related information including additional documentation on a wiki and a bulletin board. In addition, the BCI2000 project has organized a number of workshops on the theory and application of the platform: Albany, New York, June 2005; Beijing, China, July 2007; Rome, Italy, December 2007; Utrecht, The Netherlands, July 2008; Bolton Landing, New York, October 2009; and Beijing, China, December 2009.

BCI2000 Benefits

Implementation of real-time software that integrates data acquisition, signal processing, and feedback is complex and difficult. BCI2000 is a platform in which the major technical difficulties have been solved. Thus, it allows a scientist or engineer to spend more time on their research and less time on validating and trouble-shooting the technology. In addition, BCI2000 offers several other important benefits:

- **An Established Solution** BCI2000 comes with proven support for different data acquisition hardware, signal processing routines, and experimental paradigms.
- **Facilitates Operation of Research Programs** Although a number of software platforms, such as Matlab or LabView, can be used to prototype experimental

paradigms, such prototypes do not have the common data format, software interfaces, or documenting protocols, that are important or even critical for success in large research programs. In contrast, BCI2000 has been designed from the start and developed over many years to support large research programs with many diverse research projects.
- **Facilitates Deployment in Multiple Sites** The BCI2000 platform does not rely on 3rd-party software components for its operation. Even for compilation, it requires only affordable or free C++ compilers. Thus, both development and deployment of BCI2000 on multiple computers in multiple sites is very economical.
- **Cross-platform/compiler Compatibility** BCI2000 currently requires Microsoft Windows to operate and Borland's C++ Builder for compilation. BCI2000 V3.0 also supports VisualStudio and MinGW.
- **Open License** BCI2000 is free and without restrictions for academic and research purposes.

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Core Team

Project Leader	Gerwin Schalk, Ph.D.
Chief Software Engineer	Jürgen Mellinger, M.E.
Quality Control and Testing	Adam Wilson, Ph.D.

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Albany, New York, USA *Gerwin Schalk*
Tübingen, Germany *Jürgen Mellinger*

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