BCI2000 NEWSLETTER

The **BCI2000** Project

BCI2000 is a general-purpose platform for Brain-Computer Interface (BCI) research. It can also be used for data acquisition, auditory and visual stimulus presentation, and brain monitoring purposes.

The BCI2000 system has been in development since 2000. To date, BCI2000 has been adopted by more than 90 laboratories around the world that use the system for a variety of studies.

Our mission is to provide to the research community a software tool that can facilitate a wide array of real-time biosignal applications. Our vision is that BCI2000 will reduce the complexity, time, and thus cost, of conducting research in the areas of BCI research, psychophysiology, basic neuroscience, and related areas.

We have recently received NIH grant support for four years to further develop and maintain the BCI2000 system. The current state of the system, as well as the exciting plans for future development, are described in this newletter.

Gerwin Schalk
BCI2000 *Chief Evangelist*

The **BCI2000** System

Software for Brain-Computer Interfacing, Data Acquisition, Stimulus Presentation, and Brain Monitoring

CURRENT STATE OF THE PROJECT

Since its inception, the goal of the BCI2000 project has been to to create a system that can facilitate the implementation of any BCI system, to incorporate into this system support for the most commonly used BCI methods, and to disseminate the system and associated documentation to other laboratories. Over the past six years, we have pursued this goal by creating an initial implementation of the BCI2000 platform, by implementing support for a number of hardware devices, brain signals, and user applications (see below), and by creating documentation for the investigator, software engineer, and end user.

Hardware

A/D Converter Boards:
Data Translations, Inc.
National Instruments, Inc.
Measurement Computing, Inc.
Modular-EEG Systems
Amplifiers/Digitizers:
g.tec USBamp and MOBIlab
Tucker-Davis Pentusa
Biosemi
CleveMed BioRadio 150
EEG Systems:
Neuroscan, Inc.
Brain Vision
Micromed EEG Systems
Virtual Device for testing

Brain Signals

Slow Cortical Potentials (SCPs)
P300 Potentials
EEG mu/beta Rhythms (ERD/ERS) (2 methods)
ECoG Oscillations
Single-Neuron Action Potentials

User Applications

1D/2D/3D Cursor Movement (3 different tasks)
4-Choice Speller
2D Robotic Arm Control (RCS-6, Robix, Inc.)
7-Sensor Data Glove (Fifth Dimension Technologies, Inc.)
P300 Matrix Speller
Auditory + Visual Stimulus Presentation (incl. Real-Time Feedback)

At present, more than 90 laboratories around the world have adopted BCI2000. A number of successful examples of how BCI2000 can facilitate a wide array of experiments are showcased on the project website on http://www.bci2000.org. (See the call for success stories later in this newsletter.) To improve the BCI2000 system and associated documentation, and to thereby make it even easier for laboratories to be successful with BCI2000, we applied for grant support from the NIH. We recently received this grant, which will sponsor substantial further development of the system for the next four years. The exciting plans for the future evolution of BCI2000 are summarized on the next page.

Exciting Future Plans

To better address the needs of the existing and prospective users of BCI2000, we will further refine the code of the existing system so that it can support other compilers and operating systems, we will update and greatly expand the documentation and user tutorials (which we will publish on the web using a Wiki-based system), we will further improve the capacity of BCI2000 to interact with, and be controlled by, external applications, we will further develop the analysis software *Mario* to support the most common analyses, and we will conduct additional workshops on the use of the system. We expect that these efforts will facilitate BCI experiments by non-experts, as well as the creation of many data acquisition, stimulus presentation, and brain monitoring applications. Finally, we will relax the current BCI2000 license such that the executables can simply be downloaded from the Internet and parts of the system (including third-party contributions) will be put under the GPL or an equivalent open-source license. Over the next couple months, we will further describe these ambitious plans on the project web site http://www.bci2000.org.

These plans will be implemented in two steps. The first step, BCI2000 V2.0, will be completed by July 2007. This version will realize the current functionality of the system but will document all of the system's functions. The second step, BCI2000 V3.0, will be completed by the end of 2007. This version will add cross-platform and cross-compiler capacities and will add improved interoperability with other software. We envision that with version 3.0, BCI2000 will essentially become a library that can be used to realize a wide array of real-time biosignal applications with different functions and graphical interfaces.

Core Team	Additional Contributions	Sponsors
Gerwin Schalk Chief Evangelist **Jürgen Mellinger** Lead Software Engineer **Febo Cincotti** Offline Analysis and Tutorials	Erik Aarnoutse Brendan Allison Simona Bufalari Bob Cardillo Emanuele Fiorilla g.tec Thilo Hinterberger Jenny Hizver Sam Inverso Vaishali Kamat Dean Krusienski Marco Mattioco Dennis McFarland Melody M. Moore-Jackson Yvan Pearson-Lecours Mark Span Chris Veigl Janki Vora Adam Wilson Shi Dong Zheng	**Gerwin Schalk** (NIH grant EB006356) **Jonathan Wolpaw** (NIH grant EB00856)

Recent Contributions to **BCI2000**

The following sections introduce some BCI2000 developers and highlight their recent updates and contributions to BCI2000.

Jürgen Mellinger

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Lead Software Engineer
BCI2000 project

His interests include the BCI2000 project, C++ programming, and statistical source separation techniques.

CONNECTING BCI2000 TO EXTERNAL PROGRAMS

Through a communication interface called the AppConnector protocol, external programs can "wiretap" BCI2000, listening to its internal state. If required, an external program may also change BCI2000's internal state. The AppConnector uses a networking protocol, so the external program may run anywhere on a local network – it is not required to run on the same machine as BCI2000.

Application examples comprise a BCI controlled Web Browser (Mike Bensch's Nessi extension to the Mozilla browser), a small program that operates hardware attached to the computer's parallel (printer) port, and a program by Peter Brunner that converts the P3 Speller's output into simulated keypresses.

ONLINE SIGNAL PROCESSING WITH MATLAB

The Matlab environment is a widely used tool that is well suited for offline data analysis and for the development of new algorithms.

For BCI2000 users, inter-operation with Matlab is possible in a variety of ways:

- Existing BCI2000 filters may be cast into Matlab-compatible "DLLs", i.e., blocks of compiled code that may be executed from Matlab to operate on data that is present inside Matlab.
- BCI2000 comes with a Matlab plug-in module (called `load_bcidat`) that reads BCI2000 data files directly into Matlab. Whenever the BCI2000 file format gets updated, there will be an updated version of that plug-in module that is ready to handle the latest file format.
- As the latest development, BCI2000 can now perform on-line processing with Matlab. Data, once recorded by BCI2000, may be intercepted and processed by Matlab at any stage of processing, then fed back into BCI2000 for further processing and feedback display.

Consider the implementation of a novel signal processing algorithm that is first implemented in Matlab. In the first stage, this algorithm may operate offline on existing data that have been recorded by BCI2000, and then read into Matlab using the `load_bcidat` routine.

Once the new algorithm works as expected for off-line data, it is easy to incorporate it online within BCI2000. For this purpose, it needs to be packed into Matlab functions that interface with BCI2000. A single Matlab function does the main processing, accompanied by a number of helpers for initialization, parameterizing, and parameter checking.

As a next step, you may want to transform your Matlab-implemented algorithm into a C++ version, e.g., to use computational and/or memory resources of your system more efficiently, allowing for more channels or a higher sampling rate in the online case. Porting an algorithm from Matlab to C++ is not a trivial task, but this process is greatly facilitated by the possibility to directly compare the results of the C++ version to that of the Matlab version.

In order to achieve this comparison, you might build your C++ version as a DLL, and call the DLL from Matlab, then compare the DLL's results with the Matlab results. Finally, the C++ version may be put into a BCI2000 Signal Processing module without additional effort, ready for efficient on-line processing.

MOVING BCI2000 TOWARDS "STANDARD C++"

Over the past years, standardization of the C++ language has made considerable progress. Unlike a few years ago, all main compilers now agree on all important features of the language. Moreover, it is now possible to use the C++ standard library in a way that is compatible across implementations and platforms.

The BCI2000 framework has been moving towards a more "standard" usage of C++ for some time. In fact, compatibility of important BCI2000 framework code with compilers such as gcc 3, VC++, or MinGW has been a target of efforts over the past months.

As a result of these efforts, a VC++/MFC-based application module exists (see next section). Full cross-platform compatibility is expected over the next year with BCI2000 V3.0. Practically important, the `load_bcidat` Matlab mex file has been compiled successfully under MacOS X (Peter Brunner) and Linux (Adam Wilson).

DEVELOPING MFC-BASED APPLICATION MODULES

Although most of BCI2000 does not depend on GUI elements such as windows, controls, or graphics shapes, BCI2000 application modules typically require some amount of interfacing with the operating system for which no abstractions exist in the C++ standard libraries. Such interfacing is provided by additional libraries called "Application Frameworks". For MS-Windows based applications, the most influental and most widely used Application Framework are the "Microsoft Foundation Classes" (MFC) that come with Microsoft's Visual C++ compiler.

Since its inception, BCI2000 has relied on Borland's C++ Builder Development Environment and the associated VCL Application Framework. To facilitate BCI2000 application development for developers who prefer the MFC framework, BCI2000 includes an MFC-based demo application that serves as a starting point for developing application modules under Microsoft Visual C++.

Adam Wilson

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Over the past year, Adam has worked on several programs for BCI2000, including a source module for the Tucker-Davis Technology system, a Matlab plugin for importing BCI2000 data into EEGlab, and a graphical user interface program called BCILauncher for launching and organizing the necessary BCI2000 modules automatically.

The TDT driver was incorporated into BCI2000 last summer, and supports the Tucker Davis RX5 Pentusa system. This system is capable of recording up to 64 channels simultaneously at sampling rates of at up to at least 1 kHz (the highest tested so far). In addition, the system can perform online digital filtering, including a bandpass anti-aliasing filter and a line notch filter. We have successfully used the Pentusa with our EEG and ECoG experiments. In the future, we plan to use BCI2000 and the Pentusa systems for experiments incorporating local field potentials (LFPs) and/or cortical action potential recordings.

EEGlab is a widely used toolbox developed at UCSD (Scott Makeig and Arno Delorme) for the analysis of EEG and ECoG signals. It simplifies performing advanced operations such as coherence analysis, event-related (de)synchronization measurements, and independent component analyses. The BCI2000 plugin for EEGLab allows the user to select one or more BCI2000 datasets for importing. All BCI2000 system states (such as *TargetCode*, *Feedback*, and *IntertrialInterval*) are imported as events for epoching and averaging.

BCILauncher serves to provide a simple user interface for launching the necessary BCI2000 modules (signal acquisition, signal processing, application, and the operator), and serves as an alternative to using multiple batch files or starting each module independently. All modules are launched and automatically connect to the operator. In addition, a previously defined parameter file can be selected and loaded immediately, decreasing the time for starting a frequently-used paradigm.

Dean J. Krusienski, Ph.D.

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Assistant Professor
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His research interests include the development of signal processing and computational intelligence methods for application to brain-computer interfaces and biomedical systems.

Dr. Krusienski has been working with BCI2000 since 2004. He has recently developed the Matlab-based P300 GUI tool. It was developed for linear classifier design and visualization of evoked potential data collected with the BCI2000 P3Speller and P3AV paradigms. The P300 GUI is capable of performing several functions independently:

Classifier Training: Using BCI2000 data, the P300 GUI can generate feature weights for a linear classifier that detects evoked potentials. Various regression methods and data preprocessing options for training the classifier can be selected and manipulated using the GUI. The resulting feature weights can be saved and imported into BCI2000 for online evaluation.

Classifier Testing: The P300 GUI can apply a set of current or previously created feature weights to independent BCI2000 data for comparison of the offline classification performance.

Visualizing Evoked Potentials: The P300 GUI can visualize the spatio-temporal correlation patterns, the temporal averages, and the spatial topographies of evoked potentials collected using BCI2000.

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Offline Analyses and Tutorials, BCI2000 project

His research interests include neuroelectrical inverse problem, high-resolution EEG processing, BCI systems and their clinical application, and the MARIO project for BCI2000.

The MARIO project aims at complementing BCI2000 by building a tool for offline analyses of brain signals acquired using BCI2000. The combination of graphical and script-based use provides a rapid learning curve and facilitates more comprehensive analyses.

MARIO is modular and object-oriented, and can be easily integrated with other software packages for data analysis and visualization. MARIO can be used for the analysis of data acquired with a BCI2000 environment in mu-rhythm and P300 setups. It is targeted towards two classes of uses – routine analysis by non-experts and more comprehensive analyses by experts in signal analysis. The first use benefits from a Graphical User Interface (GUI) that guides users through standard analysis processes. The second use benefits from software modules that are available for batch processing. This capacity will facilitate (i) repeating the same analysis on a large number of recordings; (ii) performing exhaustive analyses (using different parameters) on a specific dataset; (iii) experimenting with custom algorithms with no need to re-implement the entire processing pipeline.

The joint use of BCI2000 and MARIO allows individual groups with specific expertise or consortia of groups with complementary expertise to carry on research in one of the disciplines that compose BCI research, without being forced to acquire detailed competence in all of the others. As an example, a group involved in machine learning could study a new classification strategy by simply plugging their new analysis technique into the analysis pipeline of MARIO or BCI2000, respectively, or a group involved in assistive technology could test the effectiveness of their brain-controlled keyboard in a clinical environment.

BCI2000 WORKSHOPS IN 2007 AND 2008: CALL FOR PROPOSALS

In June of 2005, we conducted the 1st BCI2000 Workshop. This workshop was attended by 44 participants from 24 laboratories in 11 countries. The first day covered theoretical aspects of BCI operation in general and of BCI2000 specifically. The second day was devoted to hands-on BCI operation. The photo below shows an impression from this successful event.

We are currently beginning to plan the 2nd and 3rd BCI2000 Workshops. Ideally, these workshops will be satellite events to existing conferences that attract scientists in BCI research and those interested in other real-time biosignal processing applications. To select an appropriate venue, we ask for proposals to host these events. Please send them to workshop@bci2000.org.

The BCI2000 project will provide speakers and all workshop material (including data acquisition hardware) and pay for flight and lodging of speakers. We would hope that the host assists with selection of an appropriate venue and with advertising of the event. Just like in the first workshop, we plan to cover meeting expenses (e.g., rent for venue and meals for participants) through registration fees.

CALL FOR BCI2000 SUCCESS STORIES

We are currently featuring some of the successful implementations of BCI2000 on the project web site (www.bci2000.org). We would like to inform current or prospective users (and ourselves) better about the number and diversity of applications that BCI2000 supports. To this end, we call for success stories (in a format similar to those on the web site) that highlight the use of BCI2000 and resulting accomplishments of a particular research group. Please send us your success story by November 15. We will then post a select number of these stories on the project web site.