INTRODUCTION

Advances in cognitive neuroscience and brain-imaging technologies give us the unprecedented ability to interface directly with brain activity. These technologies let us monitor the physical processes in the brain that correspond to certain forms of thought. Driven by society’s growing recognition of the needs of people with physical disabilities, researchers have begun using these technologies to build Brain Computer Interface (BCI) communication systems that do not depend on the brain’s normal output pathways of peripheral nerves and muscles.

In Brain Computer Interface (BCI), users explicitly manipulate their brain activity instead of motor movements to produce signals that control computers or communication devices. This research has extremely high impact, especially for disabled individuals who cannot otherwise physically communicate. For several years, research groups in Europe and the USA have been working on systems which allow for a direct dialog between man and machine. To this end, a "Brain Computer Interface" (BCI) has been developed.

![Fig 1. The user has an EEG cap on. By thinking about left and right hand movement the user controls the virtual keyboard with her brain activity.](image)

A **Brain Computer Interface (BCI)**, sometimes called a **Direct Neural Interface** or a **Brain Machine Interface** is a direct communication pathway between a human or animal brain (or brain cell culture) and an external device. Cerebral electric activity is recorded via the electroencephalogram (EEG) electrodes attached to the scalp which measure the electric signals of the brain. These signals are amplified and transmitted to the computer and then transformed into device control commands. Electric activity on the scalp reflects motor intentions. BCI detects the motor-related EEG changes and uses this data to operate devices which are connected to the computer.

BACKGROUND
In the past decade, inspired by the remarkable advances in neuroscience, electronic and computer technology, research groups around the world have begun to develop Brain Computer Interface (BCI) that provides direct communication and control channels between the brain and the external world. The action potential of single neuron (‘spike’) or the scalp electrical signal (EEG) are collected and translated into commands that move robot arms, wheelchairs, and cursors on the computer screen. The development of microelectrode arrays has allowed researchers in the field to start thinking seriously about a variety of next-generation neuro-prostheses, including vision prostheses for the blind and brain-computer interfaces for the totally paralyzed. These should be considered as a compensation and expansion of the output channel of brain.

On the other direction, the input channel, by using electrical brain stimulation to deliver both ‘virtual’ tactile cues and rewards to freely roaming rats, people have been able to instruct animals remotely to navigate through complex mazes and natural environments. Through the two-way BCI, people are trying to understand the mechanism of brain by building artificial communication channels. Also, to some extent, the power of brain is released from the constraint of innate limitation, which possibly make locked people unlocked and health people more intelligent and powerful. Here we are going to explore the possibility of establishing a direct brain-to-brain communication channel, which may be a pilot work of two-way prosthesis of the brain function.

Brain Computer Interfaces are hardware and software systems that sample electro-encephalogram (EEG) signals from electrodes placed on the scalp and extract patterns from EEG that indicate the mental activity being performed by the person. The crucial requirement for the successful functioning of the BCI is that the electric activity on the scalp surface already reflects motor intentions, i.e., the neural correlate of preparation for hand or foot movements. The BCI detects the motor-related EEG changes and uses this information, for example, to perform a choice between two alternatives: the detection of the preparation to move the left hand leads to the choice of the first, whereas the right hand intention would lead to the second alternative. By this means it is possible to operate devices which are connected to the computer. A Brain Computer Interface (BCI) is a novel communication system that translates human thoughts or intentions into a control signal.

Brain Computer Interfaces (BCIs) enable motor disabled and healthy persons to operate electrical devices and computers directly with their brain activity. BCI recognizes and classifies different brain activation patterns associated with real movements and movement attempts made by tetraplegic persons. A Brain-Computer Interface (BCI) is a communication system in which messages or commands that a user wishes to convey pass not through the brain's normal output pathways to the muscles but are instead extracted directly from brain signals. The basis for this is that mental activity (thought) can modify the bioelectrical brain activity and is therefore encoded in the recorded signals. In this way, a BCI provides a new, non-muscular communication channel that system developers can use in a variety of applications, such as assisting people with severe motor disabilities, supporting biofeedback training in people suffering from epilepsy, stroke, or controlling computer games.

GENERAL PRINCIPLE
In healthy subjects, the primary motor area of the brain sends movement commands to the muscles via the spinal cord.

In many paralyzed people, this pathway is interrupted, that is due to a spinal cord injury.

A new treatment is being researched: Electrodes measure activity from the brain. A computer-based decoder translates this activity into commands for the control of muscles, a prosthesis or a computer.

Fig. 2. The general principle underlying Brain Computer Interfaces.

Scientific progress in recent years has successfully shown that, in principle, it is feasible to drive prostheses or computers using brain activity. The focus of worldwide research in this new technology, known as Brain Machine Interface or Brain Computer Interface, has been based on two different prototypes: Non-invasive Brain Machine Interfaces, which measure activity from large groups of neurons with electrodes placed on the surface of the scalp (EEG), and Invasive Brain Machine Interfaces, which measure activity from single neurons with miniature wires placed inside the brain. Every mental activity—for example, decision making, intending to move, and mental arithmetic—is accompanied by excitation and inhibition of distributed neural structures or networks. With adequate sensors, we can record changes in electrical potentials, magnetic fields, and (with a delay of some seconds) metabolic supply.

Consequently, we can base a Brain Computer Interface on electrical potentials, magnetic fields, metabolic or haemodynamic recordings. To employ a BCI successfully, users must first go through several training sessions to obtain control over their brain potentials (waves) and maximize the classification accuracy of different brain states. In general, the training starts with one or two predefined mental tasks repeated periodically. In predefined time we record the brain signals and use them for offline analyses. In this way, the computer learns to recognize the user’s mental-task-related brain patterns. This learning process is highly subject-specific, so each user must undergo the training individually. Visual feedback has an especially high impact on the dynamics of brain oscillations that can facilitate or deteriorate the learning process.

**SCHEMATIC OF A BRAIN COMPUTER INTERFACE**
Brain Computer Interface (BCI) is a collaboration between a brain and a device that enables signals from the brain to direct some external activity, such as control of a cursor or a prosthetic limb. The interface enables a direct communication pathway between the brain and the object to be controlled. In the case of cursor control, for example, the signal is transmitted directly from the brain to the mechanism directing the cursor, rather than taking the normal route through the body's neuromuscular system from the brain to the finger on a mouse.

Fig 3. Schematic of a Brain Computer Interface (BCI) System.

By reading signals from an array of neurons and using computer chips and programs to translate the signals into action, Brain Computer Interface can enable a person suffering from paralysis to write a book or control a motorized wheelchair or prosthetic limb through thought alone. Current Brain-Interface devices require deliberate conscious thought; some future applications, such as prosthetic control, are likely to work effortlessly. One of the biggest challenges in developing Brain Computer Interface technology has been the development of electrode devices and surgical methods that are minimally invasive. In the traditional Brain Computer Interface (BCI) model, the brain accepts an implanted mechanical device and controls the device as a natural part of its representation of the body. Much current research is focused on the potential on non-invasive Brain Computer Interfaces.

**COMPONENTS OF A BRAIN COMPUTER INTERFACE**
INVASIVE OR NON INVASIVE SIGNAL RECORDINGS

In the invasive signal recordings, electrodes are placed in the cortex (intra-cortical recording) or on the cortex (sub-dural recording) and in the non-invasive signal recordings, electrodes are fixed on the intact skull. Invasive signal recording is less vulnerable to artifacts and has the advantage of an excellent signal-to-noise ratio.

TYPE OF SIGNAL

In the electroencephalogram (EEG) and electrocorticogram (ECoG), two types of phenomena can be differentiated between, either event-related potential changes (evoked potential, slow cortical potential shifts) or event-related changes in ongoing EEG (ECoG) in specific frequency bands (event-related de/synchronization).

MENTAL STRATEGY

The mental strategy defines the way that the bioelectrical brain activity is modified. Operant conditioning, focused visual attention and motor imagery are strategies in BCI research. Experiments have shown that after a training period, the user can obtain control over specific components of oscillatory activity in the EEG.

MODE OF OPERATION

The mode of operation determines when the user performs a mental task and, therewith, intends to transmit a message. In principle, there are two distinct modes of operation, the first being externally-paced (cue-based, computer-driven, asynchronous BCI) and the second internally-paced (uncued, user-driven, asynchronous BCI).

TYPE OF FEEDBACK (FB)

Feedback is a very important component in the training phase and during application. Feedback can be discrete or continuous, realistic (e.g. hand grasp) or virtual, 1D, 2D or 3D. Together with the FB, the BCI forms a closed loop system composed of two adaptive controllers (brain and the computer).

FEATURE EXTRACTION AND CLASSIFICATION -

The goal of the feature extraction components is to find a suitable representation of the bioelectric brain signal that simplifies the subsequent classification or detection of specific thought-related patterns of brain activity. The signal feature should encode the commands sent by the user, but not contain noise and other signal components that can impede the classification process. The task of the classifier is to use the signal features to assign each recorded sample of the signal to a given class of mental patterns.

ANIMAL BRAIN COMPUTER INTERFACE RESEARCH
Several laboratories have managed to record signals from monkey and rat cerebral cortices in order to operate Brain Computer Interfaces to carry out movement. Monkeys have navigated computer cursors on screen and commanded robotic arms to perform simple tasks simply by thinking about the task and without any motor output.

**EARLY WORK**

Studies that developed algorithms to reconstruct movements from motor cortex neurons, which control movement, date back to the 1970s. Work by groups in the 1970s established that monkeys could quickly learn to voluntarily control the firing rate of individual neurons in the primary motor cortex via closed-loop operant conditioning. There has been rapid development in BCIs since the mid-1990s. Several groups have been able to capture complex brain motor centre signals using recordings from neural ensembles (groups of neurons) and use these to control external devices.

**PROMINENT RESEARCH SUCCESSES**

The first Intra-Cortical Brain-Computer Interface was built by implanting neurotrophic-cone electrodes into monkeys. In 1999, researchers decoded neuronal firings to reproduce images seen by cats. The team used an array of electrodes embedded in the thalamus of sharp-eyed cats. Researchers targeted 177 brain cells in the thalamus lateral geniculate nucleus area, which decodes signals from the retina. Neural ensembles are said to reduce the variability in output produced by single electrodes, which could make it difficult to operate a Brain Computer Interface. After conducting initial studies in rats during the 1990s, researchers developed Brain Computer Interfaces that decoded brain activity in owl monkeys and used the devices to reproduce monkey movements in robotic arms. Researchers reported training rhesus monkeys to use a Brain Computer Interface to track visual targets on a computer screen with or without assistance of a joystick (Closed-Loop Brain Computer Interface).

A Brain Computer Interface for three-dimensional tracking in virtual reality was developed and also reproduced Brain Computer Interface control in a robotic arm. Researchers used recordings of pre-movement activity from the posterior parietal cortex in their Brain Computer Interface, including signals created when experimental animals anticipated receiving a reward. In addition to predicting kinematic and kinetic parameters of limb movements, Brain Computer Interfaces that predict electromyographic or electrical activity of muscles are being developed. Such Brain Computer Interfaces could be used to restore mobility in paralyzed limbs by electrically stimulating muscles. A new 'wireless' approach uses light-gated ion channels such as Channelrhodopsin to control the activity of genetically defined subsets of neurons in vivo.

**HUMAN BRAIN COMPUTER INTERFACE RESEARCH**
INVASIVE BRAIN COMPUTER INTERFACES

Invasive BCI research has targeted repairing damaged sight and providing new functionality to paralyzed people. Invasive BCIs are implanted directly into the grey matter of the brain during neurosurgery. As they rest in the grey matter, invasive devices produce the highest quality signals of BCI devices but are prone to scar-tissue build-up, causing the signal to become weaker or even lost as the body reacts to a foreign object in the brain. Direct brain implants have been used to treat non-congenital (acquired) blindness. BCIs focusing on motor neuro-prosthetics aim to either restore movement in paralyzed individuals or provide devices to assist them, such as interfaces with computers or robot arms.

PARTIALLY- INVASIVE BRAIN COMPUTER INTERFACES

Partially invasive BCI devices are implanted inside the skull but rest outside the brain rather than amidst the grey matter. They produce better resolution signals than non-invasive BCIs where the bone tissue of the cranium deflects and deforms signals and have a lower risk of forming scar-tissue in the brain than fully-invasive BCIs. Light Reactive Imaging BCI devices are still in the realm of theory. These would involve implanting a laser inside the skull. ECoG is a very promising intermediate BCI modality because it has higher spatial resolution, better signal-to-noise ratio, wider frequency range, and lesser training requirements than scalp-recorded EEG, and at the same time has lower technical difficulty, lower clinical risk, and probably superior long-term stability than intra-cortical single-neuron recording. This feature profile and recent evidence of the high level of control with minimal training requirements shows potential for real world application for people with motor disabilities.

NON- INVASIVE BRAIN COMPUTER INTERFACES

There have also been experiments in humans using non-invasive neuro imaging technologies as interfaces. Signals recorded in this way have been used to power muscle implants and restore partial movement in an experimental volunteer. Although they are easy to wear, non-invasive implants produce poor signal resolution because the skull dampens signals, dispersing and blurring the electromagnetic waves created by the neurons. Electroencephalography (EEG) is the most studied potential non-invasive interface, mainly due to its fine temporal resolution, ease of use, portability and low set-up cost. But as well as the technology's susceptibility to noise, another substantial barrier to using EEG as a brain-computer interface is the extensive training required before users can work the technology. Another research parameter is the type of waves measured. In Magnetoencephalography (MEG) and functional magnetic resonance imaging (fMRI) have both been used successfully as non-invasive BCIs. fMRI measurements of haemodynamic responses in real time have also been used to control robot arms with a seven second delay between thought and movement.

CELL-CULTURE BRAIN COMPUTER INTERFACES
Researchers have built devices to interface with neural cells and entire neural networks in cultures outside animals. As well as furthering research on animal implantable devices, experiments on cultured neural tissue have focused on building problem-solving networks, constructing basic computers and manipulating robotic devices. Research into techniques for stimulating and recording from individual neurons grown on semiconductor chips is sometimes referred to as neuroelectronics or neurochips. The world first Neurochip was developed by researchers Jerome Pine and Michael Maher. Development of the first working neurochip was claimed by a Caltech team led by Jerome Pine and Michael Maher in 1997. The Caltech chip had room for 16 neurons.

**SHORT OVERVIEW OF EEG-BASED BCI SYSTEMS**

**ALBANY BCI**

In the eighties, Wolpaw started an EEG-based cursor control in normal adults using band power centered at 9 Hz. At this time the Wolpaw system in Albany is cue-based and uses autoregressive (AR) parameters. A linear equation defines the cursor movement necessary for character selection.

**TUEBINGEN BCI**

Self-regulated slow cortical potential shifts (SCP) are used by Birbaumer's group in Tuebingen to operate a Thought Translation Device. The SCP are measured in a 2-second window referred to a 2-second baseline (cue-based) and used to move a ball-like light with a target. Patients using this system are able to write text after many training sessions.

**THE GRAZ-BCI SYSTEM**

The Graz BCI System is a cue-based system with motor imagery as mental strategy and classifies oscillatory activity in the 10-Hz and 20-Hz frequency band. Parameters are band power or adaptive AR parameters.

**DONCHIN'S BCI**

The Donchin BCI is based on the presentation of a 6x6 letter matrix, in which in short intervals, one of the rows or one of the columns of the matrix is flashed. Fixation of the user to one letter/item elicits a visual EP component called P300. With this system a communication rate of about 7 items/min can be obtained.

A BCI can also be realized based on the evaluation of the amplitude of steady state VEPs induced by flickering lights. When the user focuses attention to one of more flicking lights the corresponding amplitude becomes enhanced. With this system an information transfer of up to 90 bit/min is possible.

**EEG BASED BRAIN COMPUTER INTERFACE**
FOR TETRAPLEGICS

The most immediate and practical goal of Brain Computer Interface research is to create a mechanical output from neuronal activity. The challenge of Brain Computer Interface research is to create a system that will allow patients who have damage between their motor cortex and muscular system to bypass the damaged route and activate outside mechanisms by using neuronal signals. This would potentially allow an otherwise paralyzed person to control a motorized wheelchair, computer pointer, or robotic arm by thought alone.

Fig 4. A brain actuated wheelchair. The subject guides the wheelchair through a maze using a BCI that recognizes the subject’s intent from analysis of non invasive EEG signals.

Fig 5. Neuroprosthetic device using a Brain Computer Interface.

Most Brain Computer Interfaces translate neural activity into a continuous movement command, which guides a computer cursor to a desired visual target. If the cursor is used to select targets representing discrete actions, the Brain Computer Interface serves as communication prosthesis. Examples include typing keys on a keyboard, turning on room lights, and moving a wheelchair in specific directions. Visual attention, however, might be needed for application control to drive a wheelchair, to observe the environment, etc. Feedback plays an important role when learning to use a Brain Computer Interface.

BRAIN CONTROLLED ROBOTS
The idea of moving robotic or prosthetic devices not by manual control but by mere “thinking”—that is, by human brain activity—has fascinated researchers for the past 30 years. How can brainwaves directly control external devices? Ensembles of neurons in the brain’s motor system—motor, premotor, and posterior parietal cortex—encode the parameters related to hand and arm movements in a distributed, redundant way. For humans, however, noninvasive approaches avoid health risks and associated ethical concerns.

Fig. 6. Simulation of the subject’s hand movement by a hand shaped robot.

Fig. 7. Analysis of the brain image by a computer program. (Left) Active brain areas. (Upper right) Extracted brain activity patterns. (Lower right) Pattern classification processing.

Most non-invasive Brain Computer Interfaces (BCI) use electroencephalogram (EEG) signals—electrical brain activity recorded from electrodes on the scalp. The EEG’s main source is the synchronous activity of thousands of cortical neurons. Thus, EEG signals suffer from a reduced spatial resolution and increased noise when measurements are taken on the scalp. Consequently, current EEG-based brain-actuated devices are limited by low channel capacity and are considered too slow for controlling rapid and complex sequences of robot movements. Recently, researchers had shown for the first time that online EEG signal analysis, if used in combination with advanced robotics and machine learning techniques, is sufficient for humans to continuously control a mobile robot and a wheelchair.

SPONTANEOUS EEG AND ASYNCHRONOUS OPERATION
We can classify non-invasive EEG-based BCIs as evoked or spontaneous. An evoked BCI exploits a strong characteristic of the EEG, the evoked potential, which reflects the immediate automatic responses of the brain to some external stimuli. In principle, evoked potentials are easy to detect with scalp electrodes. However, evoking them requires external stimulation, so they apply to only a limited task range. Spontaneous BCIs are based on the analysis of EEG phenomena associated with various aspects of brain function related to mental tasks that the subject carries out at will. In such asynchronous protocols, the subject can deliver a mental command at any moment without waiting for external cues.

THE STATISTICAL MACHINE LEARNING WAY

Training is a critical BCI development issue—that is, how do users learn to operate the BCI? The user and the BCI are coupled together and adapt to each other. In other words, we use machine learning approaches to discover the individual EEG patterns characterizing the mental tasks users execute while learning to modulate their brainwaves in a way that will improve system recognition of their intentions. We use statistical machine learning techniques at two levels: selecting the features and training the classifier embedded in the BCI. Incorporating rejection criteria to avoid making risky decisions is an important BCI concern.

A BLENDING OF INTELLIGENCES

How is it possible to control a robot that must make accurate turns at precise moments using signals that arrive at a rate of about one bit per second? The key aspect of our brain-actuated robots is combining the subject’s mental capabilities with the robot’s intelligence. The subject delivers a few high-level mental commands and the robot executes these commands autonomously using the readings of its onboard sensors. The EEG conveys the subject’s intent, and the robot performs it to generate smooth, safe trajectories. This approach makes it possible to continuously control a mobile robot—emulating a motorized wheelchair—along nontrivial trajectories requiring fast and frequent switches between mental tasks.

CHALLENGES AND FUTURE RESEARCH DIRECTIONS

For brain-actuated robots, in contrast to augmented communication through BCI, fast decision making is critical. Real-time control of brain-actuated devices, especially robots and neuro prostheses, is the most challenging BCI application. While researchers have demonstrated brain-actuated robots in the laboratory, the technology isn’t yet ready for use in real world situations. There is still need to improve the BCI’s robustness to make it a more practical and reliable technology. A first line of research is online adaptation of the interface to the user to keep the BCI constantly tuned to its owner. In addition, brain signals change naturally over time. In particular, they can change from one session that supplies the data to train the classifier to the next session that applies the classifier.

BRAIN COMPUTER INTERFACE VERSUS
Neuroprosthetics is an area of neuroscience concerned with neural prostheses—using artificial devices to replace the function of impaired nervous systems or sensory organs. The most widely used neuroprosthetic device is the cochlear implant, which was implanted in approximately 100,000 people worldwide as of 2006. There are also several neuroprosthetic devices that aim to restore vision, including retinal implants, etc. The differences between Brain Computer Interfaces and Neuroprosthetics are mostly in the ways the terms are used: Neuroprosthetics typically connect the nervous system, to a device, whereas Brain Computer Interfaces usually connect the brain (or nervous system) with a computer system.

Practical Neuroprosthetics can be linked to any part of the nervous system, for example peripheral nerves, while the term "Brain Computer Interface” usually designates a narrower class of systems which interface with the central nervous system. The terms are sometimes used interchangeably and for good reason. Neuroprosthetics and Brain Computer Interface seek to achieve the same aims, such as restoring sight, hearing, movement, ability to communicate, and even cognitive function. Both use similar experimental methods and surgical techniques.

Commercialization and Companies

Cyberkinetic Neurotechnology Inc, markets its electrode arrays under the BrainGate product name and has set the development of practical Brain Computer Interfaces for humans as its major goal. The BrainGate is based on the Utah Array developed by Dick Normann. Neural Signals was founded in 1987 to develop Brain Computer Interfaces that would allow paralyzed patients to communicate with the outside world and control external devices. As well as an invasive Brain Computer Interface, the company also sells an implant to restore speech. Neural Signals' Brain Communicator Brain Computer Interface device uses glass cones containing microelectrodes coated with proteins to encourage the electrodes to bind to neurons.

Avery Biomedical Devices and Stony Brook University are continuing development of the implant, which has not yet received FDA approval for human implantation. Ambient, at a TI developer’s conference in early 2008, demoed a product they have in development call The Audeo. The Audeo is being developed to create a human-computer interface for communication without the need of physical motor control or speech production. Using signal processing, unpronounced speech representing the thought of the mind can be translated from intercepted neurological signals. Mindball is a product developed and commercialized by Interactive Productline in which players compete to control a ball's movement across a table by becoming more relaxed and focused. Interactive Productline is a Swedish company whose objective is to develop and sell easy understandable EEG products that train the ability to relax and focus.

The First Commercially Available
The evolution of the Brain Computer Interface may seem to be rooted in the internal keyboard and its recent traveling companion, the mouse, but much work is being done in the areas of virtual worlds, voice recognition, handwriting recognition and gesture recognition to give us a new paradigm of computing. It now appears we are on the edge of another brave new virtual world – the direct interface between the brain and the computer is here. Now the German Guger Technologies group has taken the technology out of the laboratory and into the real world with a complete Brain Computer Interface kit, and amazingly, there’s also a kit for a pocket PC - a super-low-weight biosignal recording system “g.MOBILAB” is used to measure the EEG and the data processing, analysis and pattern recognition are performed on a commercially available Pocket PC or in this case, our windows PC.

The first Brain Computer Interface System will enable the composition and sending of messages, and control of a computer game. There’s also an invasive (implanted) option still being developed in the laboratory – this is significantly more effective and the system can already accept and process input from both the embedded array and the cap array. Though the first work in the area is focused on enabling paralyzed humans to communicate far more freely, the potential to enhance one’s communications quite freely is clearly not that far away. There’s also the potential unlocked by putting such a device into the hands of thousands of eager and capable amateurs who will no doubt broaden the understanding of the human mind with their pursuits. The Brain Computer Interface (BCI) System is nominated for the European ICT Grand Prize.

In several research projects, patients have used the device to successfully produce control signals to select letters and words or to control specific functions of a wheelchair or prosthetic device. The activity of the brain is recorded with EEG (Electroencephalogram) electrodes mounted onto the surface of the head. Guger Technologies has developed a sophisticated biosignal amplifier which allows the acquisition of the signals with very high accuracy. The amplifier is plugged into a USB port of the notebook for signal acquisition. The big advantage of the ECoG recordings is the better signal quality. Even a single electrode overlaying a specific brain region can generate a reliable control signal for a Brain Computer Interface (BCI) system. On the surface of the head the Electroencephalogram (EEG) measures the activity of millions of neuron to extract the control signal.

CURRENT DEVELOPMENTS AND FUTURE
IMPLEMENTATIONS

‘BRAINGATE’ BRAIN COMPUTER INTERFACE TAKES SHAPE

An implantable, Brain Computer Interface, has been clinically tested on humans by American company Cyberkinetics. The ‘BrainGate’ device can provide paralyzed or motor-impaired patients a mode of communication through the translation of thought into direct computer control. The technology driving this breakthrough in the Brain Machine Interface field has a myriad of potential applications, including the development of human augmentation for military and commercial purposes.

The BrainGate Neural Interface Device is a BCI that consists of an internal neural signal sensor and external processors that convert neural signals into an output signal under the users own control. The sensor consists of a tiny chip with one hundred electrode sensors each that detect brain cell electrical activity. The chip is implanted on the surface of the brain in the motor cortex area that controls movement. The computers translate brain activity and create the communication output using custom decoding software.

Fig. 8 BrainGate Brain Computer Interface takes shape.
ATR AND HONDA DEVELOPS NEW BRAIN COMPUTER INTERFACE

Advanced Telecommunications Research Institute International (ATR) and Honda Research Institute Japan Co. (HRI) have collaboratively developed a new “Brain Computer Interface” (BCI) for manipulating robots using brain activity signals. This new BCI technology has enabled the decoding of natural brain activity and the use of the extracted data for the near real-time operation of a robot without an invasive incision of the head and brain. This breakthrough facilitates greater possibilities for new types of interface between machines and the human brain. HRI and ATR have developed a system for real-time brain activity decoding and robotic control.

This research reveals that MRI-based neural decoding can allow a robot hand to mimic the subject’s finger movements (“paper-rock-scissors”) by tracking the haemodynamic responses in the brain. Although there is an approximate 7-second time lag between the subject’s movement and the robot’s mimicking movement, the researchers succeeded in gaining a decoding accuracy of 85%. This technology is potentially applicable to other types of non-invasive brain measurements such as the brain’s electric and magnetic fields and brain waves. By utilizing such methods, it is expected that the same result could be achieved with less time lag and more compact BMI system devices.

The subject in an MRI scanner makes a finger gesture, “paper,” “rock” or “scissors,” while the changes in their haemodynamic responses associated with brain activity are monitored every second. Specific signals generating paper-rock-scissors movements are extracted and decoded by a computer program, and the decoded information is transferred to a hand-shaped robot to simulate the original movement performed by the subject. While conventional machine-interfaces are operated using button switches controlled by human hands or feet, BCI uses brain activity measured by various devices and allows non-contact control of the terminal machines.

Implanted electrode arrays, and brain waves have been commonly used. In conventional BMI research efforts led by U.S. neuroscientists, invasive technologies, including electrode array implants, have been used. If advanced non-invasive BCI becomes available, users will be free from the physical burden of a surgical procedure. This research accomplishment demonstrates the possibility of such a useful application. The new BMI technology is different in that natural brain activity associated with specific movements can be decoded without using alternative brain activity.

HITACHI: COMMERCIAL MIND-MACHINE INTERFACE BY 2011

Hitachi's new neuro-imaging technique allows its operator to switch a train set on and off by thought alone, and the Japanese company aims to commercialize it within five years. And this all comes hot on the heels of a revolution in microsurgery, allowing artificial limbs to be wired to the brain by reusing existing nerves. Hitachi's system doesn't invasively co-opt the nervous system, instead using a topographic modeling system to measure blood flow in the brain, translating the images into signals that are sent to the controller. So far, this new technique only allows for simple switching decisions, but Hitachi aims to commercialize it within five years for use by paralyzed patients and those undergoing "cognitive rehabilitation."
BCI2000

BCI2000 is an open-source, general-purpose system for Brain Computer Interface (BCI) research. It can also be used for data acquisition, stimulus presentation, and brain monitoring applications. BCI2000 supports a variety of data acquisition systems, brain signals, and study or feedback paradigms. During operation, BCI2000 stores data in a common format (BCI2000 native or GDF), along with all relevant event markers and information about system configuration. BCI2000 also includes several tools for data import or conversion (e.g., a routine to load BCI2000 data files directly into Matlab) and export facilities into ASCII. BCI2000 also facilitates interactions with other software. For example, Matlab scripts can be executed in real-time from within BCI2000, or BCI2000 filters can be compiled to execute as stand-alone programs.

Furthermore, a simple network-based interface allows for interactions with external programs written in any programming language. For example, a robotic arm application that is external to BCI2000 may be controlled in real time based on brain signals processed by BCI2000, or BCI2000 may use and store along with brain signals behavioral-based inputs such as eye-tracker coordinates. Also available are the full source code and all executables, which run on most current PCs running Microsoft Windows. The complete source code is provided for the BCI2000 system. Compilation currently requires Borland C++ Builder 6.0 or Borland Development Studio 2007, but otherwise does not rely on any third-party components. BCI2000 V3.0, due in 2008, will also support other compilers such as gcc.

HAT ALLOWS COMPUTER CONTROL BY THOUGHT

An electrode-covered hat can translate brain waves into computer commands, a non-invasive thought decoder that could someday let the disabled communicate by using their brains alone, according to a new study. The hat may someday also be used to operate word processing programs or control movement of a robotic prosthesis. It looks sort of like a light-weight elastic version of an old-fashioned rubber swimming cap, with small metal disks that are connected by a ribbon cable to EEG amplifiers and the computer. Brain activity can be detected from the scalp, from the cortical surface, or from within the brain itself. Some devices are implanted into the brain, but the cap is noninvasive and poses minimal, if any, risk to the wearer.

The problem with such caps in the past is that, they pick up all sorts of brain waves, to the point where the desired ones are lost or reduced to a quiet buzz amongst the din. The new cap system, which scientists refer to as a Brain Computer Interface (BCI), has better tuning. It also has an enhanced decoder that not only conveys the user's intent to the computer, but also focuses on thought patterns determined to be successful in operating the computer. As a result, the device becomes easier for the wearer to use over time. The nervous system has tremendous ability to adapt to new needs. It is possible that areas of sensorimotor cortex deprived of their normal function might conceivably acquire a new function, such as EEG (electroencephalographic)-based cursor control, more readily. Once such devices are made available, they will profoundly improve lives of some individuals whose thoughts and desires are otherwise locked within their bodies. Both invasive and noninvasive BCI's will be beneficial to patients.
WHY USE A BRAIN COMPUTER INTERFACE IF YOU ARE HEALTHY?

BCI FOR HEALTHY USERS

A few Brain Computer Interface research and development projects envisioned healthy subjects as end users. Researchers have demonstrated BCIs intended to let healthy users navigate maps while their hands are busy. Game companies such as NeuroSky and Emotiv advertise games that allow people to move a character with conventional handheld controls and control special features through a BCI.

INDUCED DISABILITY

Healthy users might communicate via BCIs when conventional interfaces are inadequate, unavailable, or too demanding. Surgeons, mechanics, soldiers, cell phone users, drivers, and pilots can experience induced disability when hand or voice communication is infeasible. BCIs might help them request tools, access data, or perform otherwise difficult, distracting, or impossible tasks. Expert gamers often use many keys at once.

EASE OF USE IN HARDWARE

Bluetooth, the ubiquitous wireless Internet, and related technologies facilitate wireless BCIs. BCIs might eventually become more convenient and accessible than cell phones, watches, remote controls, or car dashboard interfaces. BCIs could also help people who retype words or sentences by letting them instead select, drag, or click via the BCI, thus avoiding temporarily disengaging from the keyboard. BCIs could allow sending messages without the hassle of a keyboard, microphone, or cellphone numberpad.

EASE OF USE IN SOFTWARE

The activities that control most BCIs and conventional interfaces differ fundamentally from desired outputs. However, some BCIs allow walking or turning by imagining foot or hand movements and these might offer new frontiers of usability for all users. As with other interfaces, research should address which mental activities seem most natural, easy, and pleasant for different users in different situations.

OTHERWISE UNAVAILABLE INFORMATION

Available interfaces have heavily influenced all software. Just as keyboards are inherently suited to typing and dragging, BCIs are inherently better suited to certain tasks. Software might magnify, link, remember, or jump to interesting areas of the screen or auditory space. EEG-based assessment of global attention, frustration, alertness, comprehension, exhaustion, or engagement could enable software that adapts much more easily to the user. The challenge of developing new opportunities for integrating BCI-based signals into conventional and emerging operating systems might be challenging.
IMPROVED TRAINING OR PERFORMANCE

Some BCIs train subjects to produce specific activity over sensorimotor areas, so BCI training might improve movement training or performance. Subject’s athletic and motor background and skills might influence BCI parameters. These avenues might be useful for motor rehabilitation or finding the right BCI for each user.

CONFIDENTIALITY

BCIs might be the most private communication channel possible. With other interfaces, eavesdropping simply requires observing the necessary movements. This important security problem also shows up in competitive gaming environments. For example, many console gamers have chosen an offensive football play, and then noticed an adjacent opponent select a corresponding defensive play after overt peeking.

SPEED

Relevant EEGs are typically apparent one second before a movement begins and might precede the decision to move. Future BCIs might be faster than natural pathways. Further research should provide earlier movement prediction with greater precision and accuracy, integrate predicted with actual movements smoothly, and evaluate training and side effects.

NOVELTY

Some people might use a BCI simply because it seems novel, futuristic, or exciting. This consideration, unlike most others, loses steam over time. BCIs will become more flexible, usable, or better hybridized as research continues. However, as BCIs improve, public perception will follow a pattern reminiscent of microwaves and cell phones. BCIs will first be exotic, then novel, widespread, unexceptional, and finally boring.

HEALTHY TARGET MARKETS

Most healthy Brain Computer Interface users today are research scientists, and research subjects. A few people order commercial Brain Computer Interfaces forming a crucial fifth category in which no BCI expert prepared the software or hardware for individual users. Gamers are likely early adopters. Specific military or government personnel follow technology validated elsewhere. Highly specialized users such as surgeons, welders, or mechanics are also likely second- generation adopters. More mainstream applications, such as error correction hybridized with word processors, are more distant. These approaches require new software development, much better EEG sensors, and encouraging validation. Brain Computer Interfaces might instead seem unreliable, useless, unfashionable, dangerous, intrusive, or oppressive, spurred by inaccurate reporting. Brain Computer Interfaces won’t soon replace conventional interfaces, but they might be useful to healthy users in specific situations.
BRAIN COMPUTER INTERFACE APPLICATIONS

At this time BCI systems are used by patients, by the military and in the game industry. Completely paralyzed patients can use a BCI to realize a spelling system (virtual keyboard), to install a new non-muscular communication channel. In patients with Amyotrophic Lateral Sclerosis (ALS) an information transfer rate of about 10-20 bit/min (1-2 letters/min) is reported. In patients with spinal cord injuries the normal motor output is blocked and a BCI can be used for the purpose of controlling a stimulated hand grasp neuroprosthesis.

Two examples of BCI applications are presented: One is the use of an asynchronous BCI to control the functional electrical stimulation to restore the hand grasp function in a tetraplegic patient. In this case the dynamics of brain oscillations, modified by foot motor imagery, is used for control. The other is a synchronous BCI used for control of locomotion in a virtual reality environment in form of a virtual street. Forward walking is controlled by imagination of lower leg or foot movement and the stop from walking by imagination of right hand movement.

MILITARY APPLICATIONS

The United States military has begun to explore possible applications of BCIs to enhance troop performance as well as a possible development by adversaries. The most successful implementation of invasive interfaces has occurred in medical applications in which nerve signals are used as the mechanism for information transfer. Adversarial actions using this approach to implement enhanced, specialized sensory functions could be possible in limited form now, and with developing capability in the future. Such threat potential would be limited to adversaries with access to advanced medical technology.

ETHICAL CONSIDERATIONS

Discussion about the ethical implications of Brain Computer Interfaces has been relatively muted. This may be because the research holds great promise in the fight against disability and Brain Computer Interface researchers have yet to attract the attention of animal rights groups. It may also be because Brain Computer Interfaces are being used to acquire signals to control devices rather than the other way around, although vision research is the exception to this.

This ethical debate is likely to intensify as Brain Computer Interfaces become more technologically advanced and it becomes apparent that they may not just be used therapeutically but for human enhancement. Today's brain pacemakers, which are already used to treat neurological conditions such as depression could become a type of Brain Computer Interface and be used to modify other behaviours. Neurochips could also develop further, for example the artificial hippocampus, raising issues about what it actually means to be human. Some of the ethical considerations that Brain Computer Interfaces would raise under these circumstances are already being debated in relation to brain implants and the broader area of mind control.
CONCLUSION

Modifying the human body or enhancing our cognitive abilities using technology has been a long-time dream for many people. Brain Computer Interface (BCI) is now reaching a critical stage where it could lead to the fulfillment of that dream. Yet several important issues remain to be solved on the way to a neuronal motor prosthesis that is clinically applicable in humans. An increasing amount of research tries to link the human brain with machines allowing humans to control their environment through their thoughts. It is expected that in the future, Brain Computer Interface devices will be as common as pacemakers which work involuntarily. It also opens a whole new domain of niche applications, carefully designed to exploit this novel modality’s specific affordances, perhaps in conjunction with more traditional input devices.

With the right customized software, these most severely disabled individuals will be able to communicate by typing, control assistive robots, and control devices, such as their light or television. Non-disabled individuals, who might be interested in giving up their keyboards, should look for Brain Computer Interfaces in the marketplace anytime soon. In the past, there have been a few failed attempts to commercialize non-invasive brain recording devices for playing video games, or creating mental music or art. However, the non-invasive Brain Computer Interfaces are still not as effective for playing video games as the standard hand controllers, so it is unlikely that these devices will catch on with the general public.

Most Brain Computer Interface (BCI) research focuses on restoring communication for severely disabled users. However, Brain Computer Interfaces could also treat disabilities such as stroke, autism, epilepsy, or emotional disorders, and they might even become useful to healthy users. At present, Brain Computer Interfaces have several serious drawbacks relative to conventional interfaces such as keyboards. They are much slower, less accurate, and operational only at very low bandwidths. They require cables and unfamiliar, expensive hardware, including an electrode cap. The cap requires hair gel and several minutes of preparation and cleanup. Some Brain Computer Interfaces require training, are difficult to use, and fail with some subjects or in noisy environments.

The technology to create permanent Brain Computer Interfaces is not even a decade old, and proof-of-concept tests have already demonstrated that with as few as two electrodes a brain can create a somewhat useful filtered signal, and, with many more electrodes, motion can be replicated with reasonable accuracy. Furthermore, there is evidence that the brain is not only able to produce this output, but is able to adapt to it as well. Although brain–machine interfaces are often talked about in relation to disabled people, we can expect they will also be used by the non-disabled as a means to control their environment, especially if the devices are non-invasive and no implants are needed. The prospect of implementation of Brain Computer Interfaces will bring about a revolutionary change in people’s lives and through the very miracle of science, may bring about the realization of the theme in fiction.
REFERENCES


[3] BCI-info.org


