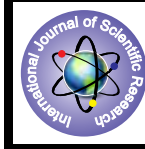


Brain Gate & Brain Computer Interface



Computer Science

KEYWORDS :

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ABSTRACT

Brain Gate was developed by the bio-tech company Cyber kinetics in 2003 in conjunction with the Department of Neuroscience at Brown University. The device was designed to help those who have lost control of their limbs, or other bodily functions. The computer chip, which is implanted into the brain, monitors brain activity in the patient and converts the intention of the user into computer commands. Currently the chip uses 100 hair-thin electrodes that 'hear' neurons firing in specific areas of the brain, for example, the area that controls arm movement. The activities are translated into electrically charged signals and are then sent and decoded using a program, thus moving the arm. According to the Cyber kinetics' website, two patients have been implanted with the Brain Gate system.

Brain Gate was developed by the bio-tech company Cyber kinetics in 2003 in conjunction with the Department of Neuroscience at Brown University. The device was designed to help those who have lost control of their limbs, or other bodily functions. The computer chip, which is implanted into the brain, monitors brain activity in the patient and converts the intention of the user into computer commands. Currently the chip uses 100 hair-thin electrodes that 'hear' neurons firing in specific areas of the brain, for example, the area that controls arm movement. The activities are translated into electrically charged signals and are then sent and decoded using a program, thus moving the arm. According to the Cyber kinetics' website, two patients have been implanted with the Brain Gate system.

The device was designed to help those who have lost control of their limbs, or other bodily functions, such as patients with amyotrophic lateral sclerosis (ALS) or spinal cord injury. The computer chip, which is implanted into the brain, monitors brain activity in the patient and converts the intention of the user into computer commands.

Currently the chip uses 100 hair-thin electrodes that sense the electro-magnetic signature of neurons firing in specific areas of the brain, for example, the area that controls arm movement. The activity is translated into electrically charged signals and are then sent and decoded using a program, which can move either a robotic arm or a computer cursor. According to the Cyberkinetics' website, three patients have been implanted with the BrainGate system. The company has confirmed that one patient (Matt Nagle) has a spinal cord injury, whilst another has advanced ALS.

In addition to real-time analysis of neuron patterns to relay movement, the Braingate array is also capable of recording electrical data for later analysis. A potential use of this feature would be for a neurologist to study seizure patterns in a patient with epilepsy.

Braingate is currently recruiting patients with a range of neuromuscular and neurodegenerative conditions for pilot clinical trials in the United States. The whole technique of this system based on mind uploading.

Mind Uploading

mind uploading (also occasionally referred to by other terms such as **mind downloading**, **mind transfer**, **whole brain emulation**, **whole body emulation**, or **electronic transcendence**) refers to the hypothetical transfer of a human mind to an artificial substrate, such as a computer simulation.

Thinkers with a strongly mechanistic view of human intelligence (such as Marvin Minsky) or a strongly positive view of robot-human social integration (such as Hans Moravec and Ray Kurzweil) have openly speculated about the possibility and desirability of this.

In the case where the mind is transferred into a computer, the

subject would become a form of artificial intelligence, sometimes called an infomorph or "*noömorph*." In a case where it is transferred into an artificial body, to which its consciousness is confined, it would also become a robot. In either case it might claim ordinary human rights, certainly if the consciousness within was feeling (or was doing a good job of simulating) as if it was the donor.

Uploading consciousness into bodies created by robotic means is a goal of some in the artificial intelligence community. In the uploading scenario, the physical human brain does not move from its original body into a new robotic shell; rather, the consciousness is assumed to be recorded and/or transferred to a new robotic brain, which generates responses indistinguishable from the original organic brain.

The idea of uploading human consciousness in this manner raises many philosophical questions which people may find interesting and disturbing, such as matters of individuality and the soul. Vitalists would say that uploading was *a priori* impossible. Many people also wonder if they were uploaded, would it be their sentience uploaded, or simply a copy?

Even if uploading is theoretically possible, there is currently no technology capable of recording or describing mind states in the way imagined, and no one knows how much computational power or storage would be needed to simulate the activity of the mind inside a computer.

Methods for Mind Uploading

True mind uploading remains speculation: the technology to perform such a feat is not currently available. A number of methods have however, been suggested to carry out mind transfers in the future.

- i. Blue Brain Project
- ii. The immortality test project
- iii. Serial sectioning
- iv. Nanotechnology
- v. "*Cyborging*"
- vi. Brain imaging
- vii. Recreating

Ethical issues of mind uploading

There are many ethical issues concerning mind uploading. Viable mind uploading technology might challenge the ideas of human immortality, property rights, capitalism, human intelligence, an afterlife, and the abrahamic view of man as created in God's image. These challenges often cannot be distinguished from those raised by all technologies that extend human technological control over human bodies, e.g. organ transplant. Perhaps the best way to explore such issues is to discover principles applicable to current bioethics problems, and question what would be permissible if they were applied consistently to a future technology. This points back to the role of science fiction in exploring such problems, as powerfully demonstrated in the 20th century by such works as *Brave New World*, *Nineteen*

Eighty-Four, Dune and Star Trek, each of which frame current ethical problems in a future environment where those have come to dominate the society.

Another issue with mind uploading is the question as to whether an uploaded mind is really the “same” sentence, or simply an exact copy with the same memories and personality. Although this difference would be undetectable to an external observer (and the upload itself would probably be unable to tell), it could mean that uploading a mind would actually kill it and replace it with a clone. Some people would be unwilling to upload themselves for this reason. If their sentence is deactivated even for a nanosecond, they assert, it is permanently wiped out. Some more gradual methods may avoid this problem by keeping the uploaded sentence functioning throughout the procedure.

To control all signals passed through mind into computer, we need one Interface. We known this interface as “Brain Computer Interface”.

Brain Computer Interface:

A **brain-computer interface (BCI)**, sometimes called a **direct neural interface** or a **brain-machine interface**, is a direct communication pathway between a brain and an external device. BCIs are often aimed at assisting, augmenting or repairing human cognitive or sensory-motor functions.

Research on BCIs began in the 1970s at the University of California Los Angeles (UCLA) under a grant from the National Science Foundation, followed by a contract from DARPA. The papers published after this research also mark the first appearance of the expression *brain-computer interface* in scientific literature.

The field of BCI has since blossomed spectacularly, mostly toward neuroprosthetics applications that aim at restoring damaged hearing, sight and movement. Thanks to the remarkable cortical plasticity of the brain, signals from implanted prostheses can, after adaptation, be handled by the brain like natural sensor or effector channels.^[3] Following years of animal experimentation, the first neuroprosthetic devices implanted in humans appeared in the mid-nineties.

BCI versus neuroprosthetics

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, as of 2006, has been implanted in approximately 100,000 people worldwide.^[4] There are also several neuroprosthetic devices that aim to restore vision, including retinal implants.

The differences between BCIs and neuroprosthetics are mostly in the ways the terms are used: neuroprosthetics typically connect the nervous system to a device, whereas BCIs 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 “BCI” 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 BCIs 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.

Animal BCI research



Rats implanted with BCIs in Theodore Berger's experiments—Several laboratories have managed to record signals from monkey and rat cerebral cortices in order to operate BCIs 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. In May 2008 photographs that showed a monkey operating a robotic arm with its mind at the Pittsburgh University Medical Center were published in a number of well known science journals and magazines. Other research on cats has decoded visual signals.

Early work

The operant conditioning studies of Fetz and colleagues first demonstrated that monkeys could learn to control the deflection of a biofeedback meter arm with neural activity^[7]. Such work in the 1970s established that monkeys could quickly learn to voluntarily control the firing rates of individual and multiple neurons in the primary motor cortex if they were rewarded for generating appropriate patterns of neural activity.^[8]

Monkey operating a robotic arm with brain-computer interfacing Studies that developed algorithms to reconstruct movements from motor cortex neurons, which control movement, date back to the 1970s. In the 1980s, Apostolos Georgopoulos at Johns Hopkins University found a mathematical relationship between the electrical responses of single motor-cortex neurons in rhesus macaque monkeys and the direction that monkeys moved their arms (based on a cosine function). He also found that dispersed groups of neurons in different areas of the brain collectively controlled motor commands but was only able to record the firings of neurons in one area at a time because of technical limitations imposed by his equipment.^[9]

There has been rapid development in BCIs since the mid-1990s.^[10] 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, including research groups led by Richard Andersen, John Donoghue, Phillip Kennedy, Miguel Nicolelis, and Andrew Schwartz.

Prominent research successes

Phillip Kennedy and colleagues built the first intracortical brain-computer interface by implanting neurotrophic-cone electrodes into monkeys.

Yang Dan and colleagues' recordings of cat vision using a BCI implanted in the lateral geniculate nucleus (top row: original image; bottom row: recording)

In 1999, researchers led by Yang Dan at University of California, Berkeley decoded neuronal firings to reproduce images seen by cats. The team used an array of electrodes embedded in the thalamus (which integrates all of the brain's sensory input) of sharp-eyed cats. Researchers targeted 177 brain cells in the thalamus lateral geniculate nucleus area, which decodes signals from the retina. The cats were shown eight short movies, and their neuron firings were recorded. Using mathematical filters, the researchers decoded the signals to generate movies of what the cats saw and were able to reconstruct recognizable scenes and moving objects.^[11] Similar results in humans have been since then achieved by researchers in Japan (see below).

Miguel Nicolelis has been a prominent proponent of using multiple electrodes spread over a greater area of the brain to obtain neuronal signals to drive a BCI. Such neural ensembles are said to reduce the variability in output produced by single electrodes, which could make it difficult to operate a BCI.

After conducting initial studies in rats during the 1990s, Nicolelis and his colleagues developed BCIs that decoded brain activity in owl monkeys and used the devices to reproduce monkey movements in robotic arms. Monkeys have advanced reaching and grasping abilities and good hand manipulation skills, making them ideal test subjects for this kind of work.

By 2000, the group succeeded in building a BCI that reproduced owl monkey movements while the monkey operated a joystick or reached for food.^[12] The BCI operated in real time and could also control a separate robot remotely over Internet protocol. But the monkeys could not see the arm moving and did not receive any feedback, a so-called open-loop BCI.

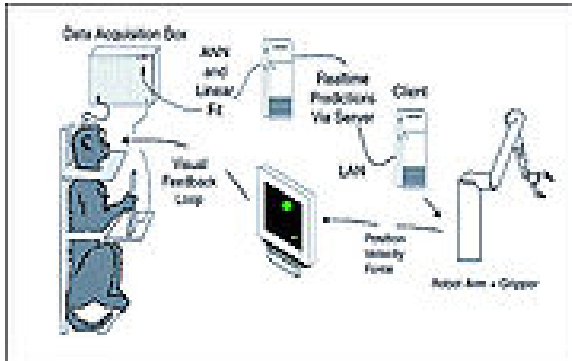


Diagram of the BCI developed by Miguel Nicolelis and colleagues for use on Rhesus monkeys

Later experiments by Nicolelis using rhesus monkeys, succeeded in closing the feedback loop and reproduced monkey reaching and grasping movements in a robot arm. With their deeply cleft and furrowed brains, rhesus monkeys are considered to be better models for human neurophysiology than owl monkeys. The monkeys were trained to reach and grasp objects on a computer screen by manipulating a joystick while corresponding movements by a robot arm were hidden.^{[13][14]} The monkeys were later shown the robot directly and learned to control it by viewing its movements. The BCI used velocity predictions to control reaching movements and simultaneously predicted hand gripping force.

Other labs that develop BCIs and algorithms that decode neuron signals include John Donoghue from Brown University, Andrew Schwartz from the University of Pittsburgh and Richard Andersen from Caltech. These researchers were able to produce working BCIs even though they recorded signals from far fewer neurons than Nicolelis (15–30 neurons versus 50–200 neurons).

Donoghue's group reported training rhesus monkeys to use a BCI to track visual targets on a computer screen with or without assistance of a joystick (closed-loop BCI).^[15] Schwartz's group created a BCI for three-dimensional tracking in virtual reality and also reproduced BCI control in a robotic arm.^[16] The group created headlines when they demonstrated that a monkey could feed itself pieces of zucchini using a robotic arm controlled by the animal's own brain signals.^{[17][18]}

Andersen's group used recordings of premovement activity from the posterior parietal cortex in their BCI, including signals created when experimental animals anticipated receiving a reward.^[19]

In addition to predicting kinematic and kinetic parameters of limb movements, BCIs that predict electromyographic or electrical activity of muscles are being developed.^[20] Such BCIs could be used to restore mobility in paralyzed limbs by electrically stimulating muscles.

Miguel Nicolelis worked with John Chapin, Johan Wessberg, Mark Laubach, Jose Carmena, Mikhail Lebedev, Antonio Pereira, Jr., Sidarta Ribeiro and other colleagues showed that activity of large neural ensembles can predict arm position. This work made possible creation of brain-machine interfaces — electronic devices that read arm movement intentions and translate them into movements of artificial actuators. Carmena et al. (2003) programmed the neural coding in a brain-machine interface allowed a monkey to control reaching and grasping movements by a robotic arm, and Lebedev et al. (2005) argued that brain networks reorganize to create a new representation

of the robotic appendage in addition to the representation of the animal's own limbs.

The biggest impediment of BCI technology at present is the lack of a sensor modality that provides safe, accurate, and robust access to brain signals. It is conceivable or even likely that such a sensor will be developed within the next twenty years. The use of such a sensor should greatly expand the range of communication functions that can be provided using a BCI.

Development and implementation of a Brain-Computer Interface (BCI) system is complex and time consuming. In response to this problem, Dr. Gerwin Schalk has been developing a general-purpose system for BCI research, called BCI2000. 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.

A new 'wireless' approach uses light-gated ion channels such as Channelrhodopsin to control the activity of genetically defined subsets of neurons in vivo. In the context of a simple learning task, illumination of transfected cells in the somatosensory cortex influenced the decision making process of freely moving mice.

Human BCI research

Invasive BCIs

Invasive BCI research has targeted repairing damaged sight and providing new functionality to persons with paralysis. 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.



Jens Naumann, a man with acquired blindness, being interviewed about his vision BCI on CBS's The Early Show

In vision science, direct brain implants have been used to treat non-congenital (acquired) blindness. One of the first scientists to come up with a working brain interface to restore sight was private researcher William Dobbelle.

Dobbelle's first prototype was implanted into "Jerry", a man blinded in adulthood, in 1978. A single-array BCI containing 68 electrodes was implanted onto Jerry's visual cortex and succeeded in producing phosphenes, the sensation of seeing light. The system included cameras mounted on glasses to send signals to the implant. Initially, the implant allowed Jerry to see shades of grey in a limited field of vision at a low frame-rate. This also required him to be hooked up to a two-ton mainframe, but shrinking electronics and faster computers made his artificial eye more portable and now enable him to perform simple tasks unassisted.



Dummy unit illustrating the design of a BrainGate interface

In 2002, Jens Naumann, also blinded in adulthood, became the first in a series of 16 paying patients to receive Dobelle's second generation implant, marking one of the earliest commercial uses of BCIs. The second generation device used a more sophisticated implant enabling better mapping of phosphenes into coherent vision. Phosphenes are spread out across the visual field in what researchers call the starry-night effect. Immediately after his implant, Jens was able to use his imperfectly restored vision to drive slowly around the parking area of the research institute.

BCIs focusing on *motor neuroprosthetics* aim to either restore movement in individuals with paralysis or provide devices to assist them, such as interfaces with computers or robot arms.

Researchers at Emory University in Atlanta led by Philip Kennedy and Roy Bakay were first to install a brain implant in a human that produced signals of high enough quality to simulate movement. Their patient, Johnny Ray (1944-2002), suffered from 'locked-in syndrome' after suffering a brain-stem stroke in 1997. Ray's implant was installed in 1998 and he lived long enough to start working with the implant, eventually learning to control a computer cursor; he died in 2002 of a brain aneurysm.^[23]

Tetraplegic, Matt Nagle became the first person to control an artificial hand using a BCI in 2005 as part of the first nine-month human trial of Cyberkinetics Neurotechnology's BrainGate chip-implant. Implanted in Nagle's right precentral gyrus (area of the motor cortex for arm movement), the 96-electrode BrainGate implant allowed Nagle to control a robotic arm by thinking about moving his hand as well as a computer cursor, lights and TV.^[24]

Partially-invasive BCIs

Partially invasive BCI devices are implanted inside the skull but rest outside the brain rather than within 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.

Electrocorticography (ECoG) measures the electrical activity of the brain taken from beneath the skull in a similar way to non-invasive electroencephalography (see below), but the electrodes are embedded in a thin plastic pad that is placed above the cortex, beneath the dura mater.^[25] ECoG technologies were first trialed in humans in 2004 by Eric Leuthardt and Daniel Moran from Washington University in St Louis. In a later trial, the researchers enabled a teenage boy to play Space Invaders using his ECoG implant.^[26] This research indicates that control is rapid, requires minimal training, and may be an ideal tradeoff with regards to signal fidelity and level of invasiveness.

(Note: These electrodes were not implanted in the patients for BCI experiments. Implanting foreign objects into people's brains solely for experimental purposes would be unethical. The patients were suffering from severe epilepsy and had the electrodes temporarily implanted to help their physicians localize seizure foci; the researchers simply took advantage of this.)

Light Reactive Imaging BCI devices are still in the realm of theory. These would involve implanting a laser inside the skull. The laser would be trained on a single neuron and the neuron's reflectance measured by a separate sensor. When the neuron fires, the laser light pattern and wavelengths it reflects would change slightly. This would allow researchers to monitor single neurons but require less contact with tissue and reduce the risk of scar-tissue build-up.

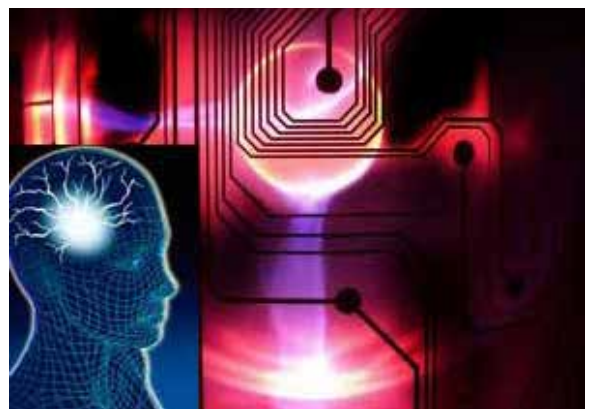
This signal can be either subdural or epidural, but is not taken from within the brain parenchyma itself. It has not been studied extensively until recently due to the limited access of subjects. Currently, the only manner to acquire the signal for vision is through the use of patients requiring invasive monitoring for localization and resection of an epileptogenic focus.

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 intracortical 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 BCIs

As well as invasive experiments, there have also been experiments in humans using non-invasive neuroimaging 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. Although the waves can still be detected it is more difficult to determine the area of the brain that created them or the actions of individual neurons.

Brain-computer Helps Paralyzed Patients



How can we make a paralyzed person perform actions that he or she wants to do? Technology is now coming to aid people who were paralyzed for long time. People with long-standing, severe paralysis can generate signals in the area of the brain responsible for voluntary movements. These signals can be detected, recorded, routed out of the brain to a computer and converted into actions, enabling a paralyzed patient to perform basic tasks. The results of the clinical trial evaluating this possibility are reported in the latest issue of *Nature*. In this study, the first patient, Matthew Nagle, a 25-year-old Massachusetts man with a severe spinal cord injury, has been paralyzed from the neck down since 2001.

After having the BrainGate sensor implanted on the surface of his brain at Rhode Island Hospital in June 2004, he learned to control a computer cursor simply by thinking about moving it. During 57 sessions, from July 2004 to April 2005, at New England Sinai Hospital and Rehabilitation Center, Nagle learned to open simulated e-mail, draw circular shapes using a paint program on the computer and play a simple video game, "neural Pong," using only his thoughts. He could change the channel and

adjust the volume on a television, even while conversing. He was ultimately able to open and close the fingers of a prosthetic hand and use a robotic limb to grasp and move objects. Despite a decline in neural signals after 6.5 months, Nagle remained an active participant in the trial and continued to aid the clinical team in producing valuable feedback concerning the BrainGate technology.....

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