BRAIN-COMPUTER INTERFACE

Brain-Computer interface is a staple of science fiction writing. Init's earliest incarnations nomenclature was thought necessary, as the technology seemed so far fetched that no explanation was likely. As more became known about the brain however, the possibility has become more real and the science fiction more technically sophisticated. Recently, the cyberpunk movement has adopted the idea of "jacking in", sliding "biosoft" chips into slots implanted in the skull (Gibson, W. 1984).

Although such biosofts are still science fiction, there have been several recent steps toward interfacing the brain and computers. Chief among these are techniques for stimulating and recording from areas of the brain with permanently implanted electrodes and using conscious control of EEG to control computers.

Some preliminary work is being done on synapsing neurons on silicon transformers and on growing neurons into neural networks on top of computer chips. The most advanced work in designing a brain-computer interface has stemmed from the evolution of traditional electrodes. There are essentially two main problems, stimulating the brain (input) and recording from the brain (output).

Traditionally, both input and output were handled by electrodes pulled from metal wires and glass tubing. Using conventional electrodes, multi-unit recordings can be constructed from mutlibarrelled pipettes. In addition to being fragile and bulky, the electrodes in these arrays are often too far apart, as most fine neural processes are only .1 to 2 µm apart.
Pickard describes a new type of electrode, which circumvents many of the problems listed above. These printed circuit micro-electrodes (PCMs) are manufactured in the same manner of computer chips. A design of a chip is photoreduced to produce an image on a photosensitive glass plate. This is used as a mask, which covers a UV sensitive glass or plastic film.

A PCM has three essential elements:

1) the tissue terminals,
2) a circuit board controlling or reading from the terminals
3) a Input/Output controller-interpreter, such as a computer.

The circuit board and computer are often located outside the skull, to minimize tissue invasion, allow for long-term implantation and permit the electrodes to be detached between trials. In addition to the ability to make multiple, closely spaced recordings, PCMs often outperform the traditional electrodes in a number of electronic measures.
The possibilities of interpreting EEG data and using it to control computers have been brought to the consumer electronics front by the IBVA, or Interactive Video Brainwave Analyzer (Nathan 1992). A headband with four adhesive electrodes sends data through a radio transmitter to a port.

The EEG is the filtered and run through a fast fourier transform before being displayed as a three dimensional graphic. The data can then be piped into MIDI compatible music programs. Furthermore, MIDI can be adjusted to control other external processes, such as robotics. The level of control provided by IBVA is limited at best and the software does not actually interpret the brain's impulses. Instead, the user must program the software to interpret consciously determined gross changes in the EEG.

The interface between the brain and computers, either through interpreting EEGs or through recording directly through PCMs is currently limited by computing strength. Conventional computers are well suited to processing linear data, but only have limited application to more distributed processes such as pattern recognition. In order to address these problems, neural net computers are modeled after the brain's complex system of weighted synapses.

The most important component is the neuron-computer chip interface.
Introduction to Bionics

Scientists have known for a long time that the human neurosystem uses electrical signals to transmit commands from the brain to the rest of the body. Now they are designing devices that speak directly to the nerves themselves. Bionics is that branch of science that helps to create a human machine interface by making use of computer technology. There was a time when Bionics was the stuff of science fiction. “We have the technology” was the theme of a popular TV series, creative writers produced fantastic stories of mechanized men, people imagined replacing body parts, improving the quality of life, revolutionizing medicine with far flung ideas like prosthetic arms, legs, mechanical eyes and ears. There’s no limit to what man has imagined. But often when people ponder these possibilities they look at them as just that, possibilities. Not everyone realizes that science fiction is quickly becoming scientific fact!

Our ultimate goal is to one day discover that faint flashing light, that ray of hope for Christopher Reeves, and the numerous other disabled who would be helped by the chance to walk, see, hear, and function like an able bodied person. This ultimate goal is to be able to connect any mechanical body part to the human brain, and have it function as a normal human organ.

The groundwork is already set for making such a possibility become a reality. Prosthetics was the first movement in this direction, allowing the brain to send signals to an artificial limb. Cochlear implants are looked at as an intermediate step. They are already in place and some of the mysteries behind them have been solved. Unlike prosthetics, Cochlear implants rely on the brain being able to both send and receive signals. Implanted electrodes stimulate nerve endings, which then allow communication with the brain. A final step is the development of the artificial eye, which when fully discovered will mean that the electrical signals can be connected directly to the nerves, which in turn will send it straight to the brain.
Bi on ic Eye

Millions of Rods and Cones are in the back of every healthy human eye. They are biological solar cells in the retina that convert light to electrical impulses - impulses that travel along the optic nerve to the brain where images are formed. Without them we are blind.

Years ago such thoughts were merely wishful. But no longer. Scientists at the Space Vacuum Epitaxy Centre (SVEC) in Houston are experimenting with thin, photosensitive ceramic films that respond to light much as rods and cones do. Arrays of such films, they believe, could be implanted in human eyes to restore lost vision. The ceramic detectors are much like ultra-thin films found in modern computer chips, so we can use our semiconductor expertise and make them in arrays - like chips in a computer factory. The arrays are stacked in a hexagonal structure mimicking the arrangement of rods and cones they are designed to replace.
Injury to the retina usually permanently impairs vision. It has been a long time since the search for a way to restore vision to people with degenerated or destroyed retinal cells started. Right now there is a hope that these two retinal diseases will be treated using silicon chips in a retinal prosthesis. Yet retinal prostheses only work for people who lost their vision through diseases—mainly the two mentioned—or an accident. For the individuals born blind, an artificial retina is not useful at all, since their visual cortex has not been trained to see. For those who have lost their sight later on in life, a bionic eye—an implant to replace the damaged and degenerated retinal cells—may restore some of their vision.

More traditional and organic solutions like gene therapy and cell transplantation have been more commonly regarded as ways to fight blindness. Therefore, biologists, surgeons and scientists hardly thought that a microelectronic chip might help save or restore sight. Studies so far have proven that microchips can be engineered for the purpose of retinal prosthesis. The main problem being faced right now is that, there are 1.2 million photoreceptors in the retina and the first step is to find an appropriate formulation and a right configuration for the microchip to suit this very delicate layer of cells.

Four groups of people are working on different projects to design and create a silicon chip to convert light and images into electrical impulses to stimulate the optical nerves so as to form the image of the objects viewed. The projects are The Artificial Retina Component Chip (ARCC), Retinal Implant Project, EPI-RET Projects and Artificial Silicon Retina (ASR). The main difference between these projects is the location the microchips are implanted: in the first three projects in front of the retina, and in the last one behind the retina. Again the first three require spectacles to be worn for video cameras and lasers but the last one does not. The last one seems to be the best one since it does not need any wires or batteries; it is very small and is even in the trial stage.
The Artificial Retina Component Chip (ARCC)

The Artificial Retina Component Chip is being developed by Dr Wentai Liu of North Carolina State University, the doctoral student Elliot McGucken of the University of North Carolina and Dr Mark Humayun of Johns Hopkins State University.

The ARCC has two main parts, a photovoltaic- powered circuit that provides photo sensing, processing, and neural stimuli and an electrode array which is at least 0.5 mm away from the retina that connects the chip to the nerve. The electrodes do not directly pass current to stimulate the nerve ganglia; instead they charge a plate that stimulates the ganglia later in turn, so as to minimize the possibility of the risk of damage to the retinal tissue.

The device works by "exciting" the remaining neurons of the retina. The silicon chip is two millimeters square, coated with photosensors and electrodes, and is 0.02 mm thick, so as to allow the light from the objects to pass through the chip to the artificial photosensors on the other side of the chip. Figure 7 shows the retinal chip along with the other component of the system.

Artificial Silicon Retina (ASR)

ASR was designed and created by brothers Alan and Vincent Chow, the co-founders of Optobionics Corporation. The silicon ship is 2mm in diameter and 1/1000 inch thick with approximately 3500 microscopic photovoltaic cells named micro photodiodes each with its own stimulating electrode.
A US biomedical engineering team has announced the development of an artificial vision system able to deliver, to a totally blind person, visual acuity of about 20/400, in a narrow visual 'tunnel.'

The system was created at the Dobelle Institute in New York City and described in the current issue of the ASAIO Journal (the journal of the American Society of Artificial Internal Organs) and in companion commentaries in Nature and Lancet.

The system uses a sub-miniature television camera and an ultrasonic distance sensor, both of which are mounted on a pair of eyeglasses. The sensors connect through a cable to a miniature computer which is worn on a belt. After processing the video and distance signals, the computer uses sophisticated computer-imaging technology, including edge-detection algorithms to simplify the image eliminating 'noise.' The computer then triggers a second microcomputer that transmits pulses to an array of 68 platinum electrodes implanted on the surface of the brain's visual cortex.
Bringing wires through the skin without discomfort or infection is one of many independent inventions that has made the new visual prosthesis possible. When stimulated, each electrode produces one to four closely spaced phosphenes, which have been described as resembling 'stars in the sky'. These white phosphenes appear on a black background 'map' which is roughly 20 cms by 5 cms at arms length.

The patient in the study reported in the ASAIO Journal is a 62-year-old male who was totally blinded by trauma when he was 36 years old. After learning to use the system and 'read' the display, the patient is now able to read two inch tall letters at a distance of five feet, representing a visual acuity of about 20/400. Although the relatively small electrode array produces tunnel vision, the patient is also able to navigate in unfamiliar environments including the New York City subway system.

After six generations of improvement over the last 21 years, the external electronics package has now been miniaturized so it is about the size of a dictionary and weighs approximately 4.5 kilos, including batteries.
For centuries, people believed that only a miracle could restore hearing to the deaf. It was not until forty years ago that scientists first attempted to restore normal hearing to the deaf by electrical stimulation of the auditory nerve. The first experiments were discouraging as the patients reported that speech was unintelligible. However, as researchers kept investigating different techniques for delivering electrical stimuli to the auditory nerve, the auditory sensations elicited by electrical stimulation gradually came closer to sounding more like normal speech.
Today, a prosthetic device, called cochlear implant, can be implanted in the inner ear and can restore partial hearing to profoundly deaf people. Some individuals with implants can now communicate without lip-reading or signing, and some can communicate over the telephone. The success of cochlear implants can be attributed to the combined efforts of scientists from various disciplines including bioengineering, physiology, otolaryngology, speech science, and signal processing. Each of these disciplines contributed to various aspects of the design of cochlear prostheses.

Signal processing, in particular, played an important role in the development of different techniques for deriving electrical stimuli from the speech signal. Designers of cochlear prosthesis were faced with the challenge of developing signal processing techniques that would mimic the function of a normal cochlea.

The Clarion cochlear implant system is the result of cooperative efforts among the University of California at San Francisco (UCSF), Research Triangle Institute (RTI) and the device manufacturer, Advanced Bionics Corporation (evolved from MiniMed Technologies). The Clarion implant supports a variety of speech processing options and stimulation patterns. The stimulating waveform can be either analog or pulsatile, the stimulation can be either simultaneous or sequential and the stimulation mode can be either monopolar or bipolar.

The Clarion processor can be programmed with either the compressed analog (CA) strategy or the CIS strategy. In the compressed analog mode, the acoustic signal is processed through eight filters, compressed and delivered simultaneously to eight electrode pairs. Analog waveforms are delivered to each electrode at a rate of 13,000 samples/sec per channel. The CA strategy emphasizes detailed temporal information at the expense of reduced spatial selectivity due to simultaneous stimulation. For
some patients, use of simultaneous stimulation results in a loss of speech discrimination due to channel interaction. This problem is alleviated in the CIS mode which delivers biphasic pulses to all eight channels in an interleaved manner.

In the CIS mode, the signal is first pre-emphasized and passed through a bank of eight bandpass filters. The envelopes of the filtered waveforms are then extracted by full-wave rectification and low-pass filtering. The envelope outputs are finally compressed to fit the patient's dynamic range and then used to modulate biphasic pulses. Pulses are delivered to eight electrodes at a maximum rate of 833 pulses/sec per channel in an interleaved fashion.

The Clarion processor (version 1.0) was recently approved by FDA, and the initial results on open-set speech recognition were very encouraging. In a recent study by Loeb and Kessler [63], thirty-two of the first 46 patients fitted with the Clarion implant obtained moderate to excellent open-set speech recognition scores (30%-100% on CID sentence test) at 12 months. Preliminary studies by Tyler et al. [64], showed that the pulsatile version (CIS) of the Clarion processor (version 1.0) obtained superior performance than the analog (CA) version of the processor. This was found to be true with six patients (one-third of the patients considered in the Tyler et al. study) who could be fitted satisfactorily with the analog version. Tyler et al. also found that Clarion patients with 9 months experience with the device performed better than Ineraid patients (using the CA strategy) and Nucleus patients (using the F0/F1/F2 strategy) with comparable experience.
William Craelius, associate professor of biomedical engineering at Rutgers, along with his students, have made breakthrough in developing a technology that will help amputees who have lost a hand. It may even allow them to perform such precise tasks as typing or playing the piano. The Dextra artificial hand, so named because of the dexterity it imparts, is a prosthesis that permits people who are missing a hand to control individual fingers using their original nerve pathways.

It uses an amputee's ability to move "phantom fingers" by harnessing the movement of the finger muscles and tendons that extend up to the elbow.
Sensors in the artificial hand pick up electrical signals generated by these muscles and tendons and transmit them to a computer that directs the hand. This new prosthesis gives the user natural control of up to five independent artificial fingers, enabling subjects to move these fingers individually.

Prior to Dextra, existing technology only allowed the user to perform grasping or holding actions, opening and closing a prosthesis by flexing or contracting a muscle. Individual finger control was not possible. The Dextra hand is being further refined to miniaturize system components and connections while hardware and software testing is ongoing.

The work is a collaboration between the Orthotics and Prosthetics Laboratory at Rutgers, Nian-Crae, Inc., of Somerset, N.J. and Creatone, Inc. of Mountainside, N.J. Nian-Crae is developing some of the software and its affiliate, Creatone, Inc., is supplying electronics components. The research is funded by grants from the National Institutes of Health through its science and technology transfer program and Nian-Crae, Inc. Rutgers is seeking additional funding sources to support further development of this program.
Computerized Prosthetic Knee (C-LEG)

C-Leg developed by Otto Bock a world leader in manufacture of prosthetic components. The C-Leg is the first computer controlled stance and swing phase prosthetic knee. The microprocessor monitors and adapts to the patient’s gait, and various terrains 50 times per second. With the combination of knee angle sensors, and force sensors in the shin section. With traditional prosthetic knee joints, people have to think (and sometimes worry) about each step they take. With the C-Leg now patients can move more freely in every-day situations, speeding up or slowing down, as they cross slopes, stairs and uneven round.

The C-Leg provides stance resistance until it senses that the patient is biomechanically safe. This is particularly useful for stepping down from a vehicle, walking down ramps, stepping off curbs, or going down stairs. The microprocessor also provides what is called stumble recovery, which is if the foot catches on the ground, or a sudden stop in motion occurs. For example if the patient is walking and had to stop for a car or an object is placed in their path all of a sudden and the knee is partially bent, the stance control would be activated and the knee would not buckle. It would allow the patient to recover with their sound leg and regain their balance. This provides for a much safer prosthesis reducing the potential for falling while allowing the patient to perform activities such as descending stairs foot over foot, and walking down inclines with out the fear of the knee buckling on them.
The optimal stability of the C-Leg equals optimal safety and ease of swing, this creates a smooth, balanced movement which imitates the movements of the individual's sound leg. In addition, the computer allows the patient to walk with a flexed knee, which is how the human limb ambulates. This reduces the shock that is transferred from heel strike up through the prosthesis into the hip socket and lower back.

It also produces a symmetrical gait that matches the human limb’s locomotion, which is that it flexes at the knee joint when the heel is placed on the ground. The C-Leg has been very successful on all levels of above knee, hip disartic, and hemipelvectomy amputations, even allowing the hip and hemipelvectomy patients to go down stairs foot over foot and have increased safety and stability. C-Leg has a second mode that can be programmed to allow the knee to be a free swing knee for bicycling, or lock in a flexed position for golf or skating. The C-Leg comes with a three year warranty. Patients worldwide have been very impressed with the C-Leg’s function and safety, our patients have concurred, and been very pleased. The incidences of falling have been reduced and their confidence has
increased, allowing them to enjoy a more active lifestyle.

In the Northern Virginia clinic Crabtree attended earlier that day to have his C-Leg refitted, his technician, Charlie Crone, booted up the software that programs it, listened for beeps from a laptop computer that feeds a cable plugged into Crabtree's prosthesis, heard the beeps, and declared, "We are connected."

The settings are fed into a computer chip in the leg that controls a special motor for a hydraulic knee. A sensor in the leg measures movements 50 times a second to adjust and guide it.

The C-Leg is made of titanium and high-strength aluminum that can support up to 330 pounds. The C-Leg includes a special "second mode" feature. Technicians can program a preset movement into the leg that can be triggered when the user taps his foot twice. The "second mode" lets an amputee golfer limit his sway when he swings a club, allows an amputee cyclist to let the leg swing free so it can rotate on pedals, and even has been used by an amputee surgeon in Texas to lock his leg in a standing position for a long surgery.

The C-Leg was approved by the Food and Drug Administration in 1999 and could help about 200,000 above-knee amputees in the United States. So far, the C-Leg's manufacturer, Germany's Otto Bock Health Care, has sold about 1,500 C-Legs in the United States, and about 3,000 worldwide, at about $40,000 a leg. The company says sales are doubling each year.

The price tag has put the C-Leg out of reach for many amputees. But that could be changing. In January Medicare and the Department of Veterans Affairs simplified plans for paying for them for qualified applicants. Otto Bock's website has a list of prosthetists across the country who are trained in fitting the C-Leg.
Future of bionics

Bionics is the future of tomorrow. The next century will see humans with bionic eye, bionic ear, bionic tongue, silicon muscles and so on. It is even predicted that it is possible to implant memory chips into the brain. And according to its design, the chip will contain specific parts for the different areas of interest, i.e., for different subjects. The model of such a chip is shown.

Memory chips that can be implanted.

This monkey in Brooklyn can move a robotic arm in North
Carolina just by thinking about it
-“thanks to bionics”
REFERENCES


