Abstract:
Thousands of people around the world suffer from paralysis, rendering them dependent on others to perform even the most basic tasks. But that could change, thanks to the latest achievements in the Brain-Computer Interface, which could help them regain a portion of their lost independence.

A four-millimetre square silicon chip studded with 100 hair-thin microelectrodes, is embedded in the primary motor cortex - the region of the brain responsible for controlling movement.

When somebody thinks “move cursor up and left” his cortical neurons fire in a distinctive pattern; the signal is transmitted through the pedestal plug attached to the skull. The signal travels to an amplifier where it is converted to optical data and bounced by fibre-optic cable to a compute. Brain Gate learns to associate patterns of brain activity with particular imagined movements—up, down, left, right—and to connect those movements to a cursor.
"We are what we think. All that we are arises with our thoughts. With our thoughts, we make the world."

1. Introduction:

Individuals with severe disabilities face challenges performing normal every-day tasks. Today, researchers are developing a technology that could conceivably alleviate many difficulties associated with physical handicaps.

Brain-Computer Interface (BCI) technology allows a living, healthy brain to connect to an external computer system through a chip composed of electrodes. The electrode chip can be implanted into defined positions within the motor cortex in order to capture the brain’s natural electric signals that stimulate voluntary movement. Researchers today can record the electrical activity of neurons firing and use computers to convert the signals into actions by applying signal processing algorithms. Significant and intensely competitive research in this field over the past decade, which one scientist has called an "arms race," has led to the first human BCI implantation surgery directed by Brown University professor, John Donoghue.
1.1 Physiology:
The brain is a tissue. It is a complicated, intricately woven tissue, like nothing else we know of in the universe, but it is composed of cells, as any tissue is. They are, to be sure, highly specialized cells, but they function according to the laws that govern any other cells. Their electrical and chemical signals can be detected, recorded and interpreted and their chemicals can be identified; the connections that constitute the brain's woven felt work can be mapped. In short, the brain can be studied, just as the kidney can.

- David H. Hubel, 1981 Nobel Prize Winner

In his statement on the brain, Hubel, a Nobel Prize recipient for his work on neurophysiology, puts forth his confidence in the potential success of researching the brain. Despite the complexity and intricacy of the connections and pathways in the brain, Hubel states that the brain is comprised of the cell, the basic foundation of any tissue. As a result, this organ, like any other, can be explored, studied, and understood. This belief and enthusiasm drive the constantly evolving knowledge and technology associated with the brain.

The brain acts as the command and control center for the human body. Its ability to integrate numerous signals to and from various sources underlies the complex behavior of humans. The brain controls basic functions like breathing, tasting, and moving but in addition, it is the basis for personality, it generates emotions and it is the center for consciousness.

1.2 The Central Nervous System

The nervous system consists of two parts, the Central Nervous System (CNS) and the Peripheral Nervous System (PNS). The brain and the spinal cord constitute the CNS and the motor and sensory nerves that lie outside the CNS constitute the PNS. The brain, weighing approximately 3 pounds, is divided into two hemispheres which are each separated into four lobes – frontal, parietal, temporal, and occipital. The frontal lobe controls reasoning, planning, speech, movement (motor cortex), emotions, and problem-solving. The parietal lobe is concerned with perception of stimuli related to touch, pressure, temperature, and pain. The temporal lobe is responsible for perception and recognition of auditory stimuli and memory while the occipital lobe focuses on vision. Measuring about 18 inches in length and weighing about 35 grams, the spinal cord is the main pathway to connect passage of information between the brain and the PNS.

1.3 The Peripheral Nervous System

The nerves that branch out from the spinal cord to the other parts of the body are called lower motor neurons (LMNs) and dorsal root sensory neurons. These spinal nerves exit and enter at each vertebral level and communicate with specific areas of the body. While the CNS functions as the main command center, deciphering signals and
determining outcomes, the PNS delivers the signals to the CNS and carries out the decisions of the CNS.

2. How does it work?
In general, there are three stages in the processing of information by the nervous system—sensory input, integration, and motor output. Sensory neurons transmit information from sensors that detect external stimuli (light, sound, heat, smell, taste, touch) and internal conditions (blood pressure, blood CO2 level, muscle tension). This information travels to the CNS where interneurons analyze and interpret (integration) the sensory input, incorporating the current circumstance with relevant situations from the past. The motor output then leaves the CNS via motor neurons which communicate with muscle or endocrine cells. An Example

The knee-jerk reflex provides an example of this process. Here is what happens. First, tapping the tendon connected to the quadriceps (extensor) muscle initiates the reflex. Sensors then detect a sudden stretch in the quadriceps. Sensory neurons convey the information to the spinal cord in addition to communicating with the motor neurons that deliver information to the quadriceps. In return, the motor neurons convey signals to the quadriceps, causing the muscle to contract and jerk the lower leg forward. The sensory neurons from the quadriceps also communicate with interneurons in the spinal cord. In response, the interneurons inhibit motor neurons that supply the hamstring (flexor) muscle. This inhibition prevents the hamstring from contracting, which would resist the action of the quadriceps.

2.1 Paralysis:
Paralysis can result from disease or trauma. It typically affects an entire region of the body although it may affect an individual muscle. The location of the nerve damage is evident from the distribution of weakness throughout the body. The two most common forms of paralysis are paraplegia (paralysis that affects both legs and trunk) and quadriplegia (paralysis that affects all four limbs and trunk.) The location of the nerve damage causing the paralysis may be in the brain or spinal cord (CNS) or the nerves outside the spinal cord (PNS.) Examples of common causes of paralysis include trauma, stroke, amyotrophic lateral sclerosis (ALS), and multiple sclerosis.
Paralysis that results in a spinal cord injury (SCI) occurs due to trauma to the spinal cord. SCIs currently affect approximately 450,000 people in the United States and in addition, more than 10,000 new cases of SCI emerge each year, one can classify a spinal cord injury as complete or incomplete. A complete injury refers to a total lack of sensory and motor function below the level of injury. In contrast, an incomplete injury means that the spinal cord has not entirely lost its ability to communicate messages to or from the brain.

People who survive a SCI will most likely suffer from medical complications such as chronic pain and bladder and bowel dysfunction in addition to an increased susceptibility to respiratory and heart problems. There is no current cure for paralysis but current research proves promising.

2.2 Paralysis and a Solution:
With paralysis, oftentimes the brain is still functioning but the signals cannot be passed along the spinal cord to the rest of the body. As a result, a means of transmitting these signals from the brain would prove to overcome the challenges that damage to the brain or spinal cord present. One avenue of research points toward brain chip technologies, specifically a brain-computer interface.

A Brain-Computer Interface (BCI) is a device that functions independently of the brain’s normal output pathways and instead processes signals from the brain to control something on a computer. The primary goal of this system is to allow people who are quadriplegic to recover a number of abilities that normally rely on their hands by connecting directly to the brain. Findings about the brain support the theoretical and practical success of the BCI. The primary motor cortex (located in the frontal lobe) is the main source of voluntary movement signals. This area is divided into specific regions to control distinct parts of the body. From studying the brain, it appears as though the control of the body parts is highly distributed within the region meaning that, for example, the neurons in the arm region as well as the neurons surrounding the arm region are capable of controlling signals for the arm. As a result, the primary motor cortex is an ideal site for the BCI because of this distribution.

3. Chip Function:

Output brain chip (or Brain-Computer Interface) technology functions by monitoring the electrical activity of a small section of the brain, mathematically interpreting the data, and relaying the new information to an action-performing device.

3.1 Listening to Neurons: Sensing Electrical Activity

As we read this article and think, the nerve cells in our brains are receiving, interpreting, and responding to a bombardment of information. The light emitted from every pixel on this page causes a different bunch of sensory
neurons in our eyes to light up in a flurry of electrical activity, conveying the text and images to the brain, while as many as 100 billion neurons network the electrical signals, forming our thoughts and directing our actions.

Neurons conduct information as electrical impulses, internal fluctuations in voltage. Normally they do this to communicate amongst themselves; however any electrical device can potentially 'speak' the language of a neuron if only it could listen closely enough. It is by listening closely that brain-computer interface technology is able to interpret the languages of our neurons.

Sensing devices for brain-computer interfaces come in two basic flavors, those internal to the skull, and those that are external. External devices sense electrical activity through the layers of skin, blood, connective tissue, and bone that separate them from their queries. However, single nerve pulses are too small and brief to be felt by a sensor outside of the head. As a result, external devices are limited to sensing whole areas of the brain at a time, limiting the usefulness of the data that they collect.

Internal sensing devices, or brain chips, can listen much more closely. Placed into the brain itself, the electrode arrays of these chips come into direct contact with live neurons, and so can sense single neuron impulses. Current methods of direct neuron sensing being tested in humans use arrays of as many as 100 micro-electrodes, recording the electrical activities of up to 96 different neurons or small groups of neurons at a time.

4. Surgical Procedure:

4.1 Surgery:

The first surgical implantation of the Brain-Computer Interface technology occurred on the morning of June 22, 2004. Dr. Gerhard Friehs, a neurosurgeon at Rhode Island Hospital and expert in gamma knife surgery, performed the implantation.

The surgery itself is a basic craniotomy. A craniotomy is the surgical removal of part of the skull to expose the brain. It is the most common procedure performed for the removal of primary brain tumors; about 35,000 adult Americans develop primary brain tumors each year.

To prepare for the procedure, magnetic resonance imaging is used to determine where on the primary motor cortex will provide the most decipherable arm-movement signals. The motor cortex, responsible for movement, is highly distributed in its control of body movements.

To begin the procedure, the patient’s scalp is shaved and he/she receives a general anesthetic. Placement of the patient’s head on a round or horseshoe-shaped headrest allows for easy accessibility. The head may be clamped
into place with a head pin fixing device to minimize movement.

The neurosurgeon begins by cutting through the scalp to reach the skull. Then, small holes (burr holes) are drilled into the exposed skull with an instrument called a perforator. To create a removable bone flap, a high speed drill named a craniotome is used to cut through the skull, moving from one burr hole to the next. This step allows for the removal of small disc of bone. With the use of a scalpel, the neurosurgeon can then cut through the protective membranes of the brain (dura, arachnoid, pia) to reach the primary motor cortex.

With the aid of a small pneumatic inserter and a plan for placement, the surgeon can place the sensor. This sensor – a tiny silicon chip about the size of a baby aspirin contains 100 electrodes, each 1 millimeter long -- is then pressed onto the surface of the cortex. The patient’s skull is closed through the replacement of the piece of excised bone with titanium screws, the muscle and skin are sutured and a drain is placed inside the brain to remove excess blood from the surgery. A tiny hole is left in the skull in order to thread gold wires from the electrode array to an external pedestal connector attached to the patient’s skull.

The risks involved with this procedure resemble that of other brain surgeries. There is a risk of brain damage (for which the surgeon will test after the operation), brain swelling, seizures, stroke, and bleeding.

5. Key players:

Roy Bakay and Philip Kennedy of Emory University have implanted two-electrode wireless implants into humans with ALS and those who had strokes in the brain stem. The implants were pieces of glass shaped like cones into which gold electrical contacts were glued. The cones were filled with a special tissue culture medium that attracts brain cells to grow toward the contacts. These implants allow individuals to move a computer cursor and to type very slowly using brain signals. Because it is wireless, no external cable is needed. However, because there are only two electrodes, a patient is limited to performing only simple tasks.
Jonathan Wolpaw and Dennis McFarland of the New York State Department of Health have created an EEG skullcap that allows patients to move a cursor up and down and side to side through the use of thoughts. Although the cap eliminates the need for an invasive surgical procedure and the risks associated, the current problem facing this device is the issue of a low signal-to-noise ratio. Because of this, the device is limited to controlling a cursor and it is unlikely that it could perform more complex tasks like controlled muscle movement.

5.1 Mapping the Brain:

As the work of Cyber kinectics has shown already, it is possible to target areas of the brain responsible for limb movement. With time, it is conceivable that the entire brain, complete with patterns of neuronal signals and neural-to-muscle relationships, will be decoded and understood with great detail. The method of transforming thought into action has already been defined. “Signal processing software algorithms analyze the electrical activity of neurons and translate it into control signals for use in various computer-based applications”. With blossoming computer technology and the development of detail-oriented, highly tuned algorithms, it is possible that we will soon live in an era in which all brain activity can be translated into, and activated in, various computer programs.

The consequences of this development are tremendous. Thought itself can soon become the driving mechanism behind many day-to-day things. Wheelchair guidance, robotic arm movement, and the variety of different resources available through computers are just the beginning. The world is no longer at the fingertips of patients, but instead exists more intimately at the neurons.

5.2 Bypassing the Spinal Cord:

Neurological study has shown us that spinal cord injury is devastating in that it results in loss of motor function without damaging either the brain or the muscles. It is this understanding that has spurred on research efforts to remove the spinal cord from the equation for movement. John Martin, Professor of Neurobiology at Columbia University has developed a procedure where a healthy nerve is transplanted across the area of injury and reconnected creating a natural bypass.

6. Spinal Cord Injury:
With a tiny electronic chip implanted in the Motor cortex of his brain, a 25-year-old man paralyzed from the neck down for five years has learned to use his thoughts to operate a computer, turn on a TV set, open email, play a video game and manipulate a robotic arm. The chip that's implanted in their brains is about the size of a baby aspirin. It has 100 electrodes, each thinner than a human hair, that pick up the electronic chatter from between 30 to 60 neurons in the motor cortex, which normally controls arm movement. The device, called the Brain Gate Neural Interface System, is produced by Cyber kinetics of Foxborough, Mass., which was originally established by Donoghue and others.

The patient imagines moving his arm to activate the neurons. The chip registers this activity, which is then converted into a program for controlling a computer cursor, TV, e-mail and other devices, and patients quickly learn how to adjust their thought processes to control the different systems. It only takes minutes, for example, for a patient to imagine moving his arm to track a moving cursor on a computer screen, and then to be able to move the cursor with his own thoughts.

Experiments with monkeys showed that the brain cells interacting with the chip become stronger with use, said University of Chicago neuroscientist Nicholas Hatsopoulos, who participated in the development of Brain Gate while at Brown and is a cofounder of Cyber kinetics.

"Animal studies show that the motor cortex does adapt as the animal learns something new," he said. "It's like learning to use a tennis racket until it becomes an Extension of your own arm."

Will normally healthy people ever be able to use a brain chip to enhance their memory, strength, vision or other functions? Hatsopoulos says that's more science fiction right now and would raise ethical issues because the procedure involves surgery to implant the device on the brain.

**7. Conclusion:**

The real application of brain chips lie in the medical world. It acts as a boon for the mentally and physically challenged people. Future could bring a revolution as brain computer interfaces are constructed using nanotechnology and getting information it becomes as easy as getting information out. It offers the possibility of hitherto and unimaginable levels of independence for the severely disabled. This, infact will be the perfect amalgamation of the machines and minds.