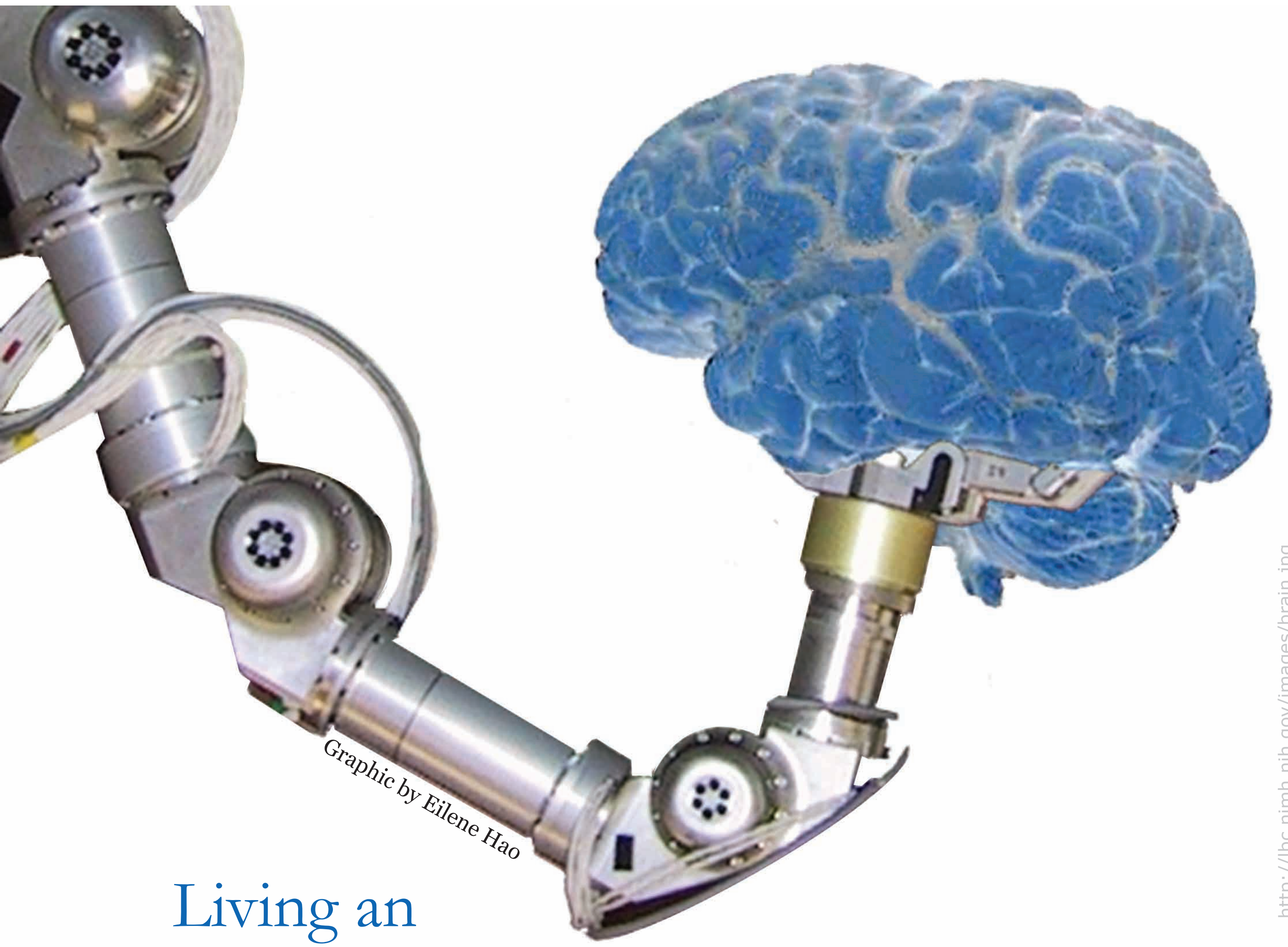


Graphic by Eilene Hao

http://lbc.nimh.nih.gov/images/brain.jpg
http://vesuvius.jsc.nasa.gov/er_er/html/era/sept2002/usgs_rob_nathan_arm.jpg

Living an Electrifying Future

by Jazib Zahir

A flash of lightning over a dark and eerie laboratory was a fitting backdrop for the creation of Frankenstein. The electrifying 'spark' needed to breathe life into an organism has been popularly conceptualized. Oonly now are we beginning to realize just how critical this spark really is to life.

Stanford: A Breeding Ground for Bioengineering Research

As biology continues to permeate technology, Stanford's new Bio-X facility has generated much hype as the ultimate marriage between the life sciences and engineering. While many of the researchers in Bio-X have been drawn to the integration of biology and their technological field simply by the availability of new facilities and funding in this area, the first seeds of this revolution were sown somewhat earlier. Many engineering research groups and medical researchers envisioned the power of technology to rapidly advance science and medicine.

Stanford's Neural Prosthetic group is one such collaboration that has earned much attention while still in the early stages of development. Joining forces between the department of Electrical Engineering and the School of Medicine's department of Neurosciences, the Neural Prosthetics group is led by Prof. Krishna Shenoy, an electrical engineer who began studying biology during his postdoctoral work at the California Institute of Technology and who continues to integrate biology with engineering in cutting edge research at Stanford.

Shenoy's Group: At the Juncture of Electrical Engineering and Biology

Shenoy's group is working at the intersection of electrical engineering and neuroscience. The engineering side involves the study of signal processing, the quantitative analysis of time-varying quantities, and the ability to transmit information through systems relying on instantaneous delivery of information in a decision-making environment. The neuroscience side involves the study of neurons, the cells that enable information to be efficiently and effectively communicated between the brain and body. The power of joining these two disciplines is that quantitative models of signal processing can be used to systematically analyze neuronal information.

The focus of Shenoy's group is to build engineering hardware that 'reads' neural activity, with the long term goal of developing functional artificial limbs for handicapped people. To be effective, the limbs need to read our brain signals indicating when and where to move. The group is thus fundamentally interested in determining how the brain collects information prior to decision-making, which parts of the brain demonstrate response, and the forms of this reponse. All of this knowledge is required in order to train artificial limbs to 'read' the brain and respond to decisions of movement.

Making the Dream a Reality

On a daily basis, people typically take motion for granted, not realizing the many bits and pieces that come together like discrete cogs in a wheel to keep us moving. There is little realization that our decision to touch this very page is preceded by a period in which the neurons decide that touch should be carried out, assess the distance of moving to the touch, and determine an appropriate speed and trajectory for physically executing the motion. These are all critical factors in the resulting effectiveness of the touch and must be taken into account by any prosthetic that is to have natural movement.

The Shenoy group is initially interested in interpreting the working of the brain as a system that despite its many intricacies can be broken down into fundamental processes mimicking the operation of a computer. The group then wishes to establish how the execution of each of the basic steps relates to the output ultimately conveyed to the limb.

The neurons of the brain contain the units of information that need to be analyzed to judge how best to extract this information from them.

It is important to select the correct part of the brain from which to study neurons, since different parts of the brain are responsible for different functions, and all are not equally relevant to the desired application. Shenoy's group has chosen to focus on the parietal reach region, believed to be the first pathway of visual information used to assess the distance from the hand to an object to be gripped. Of critical importance is that this region seems to have the ability to prioritize the order of gripping. If there were many overlapping possiblities of how to go about the touching motion, it would be hard for the electro-mechanical limb to sift through the data to find what is most relevant. Shenoy's group, however, is able to judge the order of movement that should be made from this region of the brain, and as a result provide the limb an ordered sequence of signals.

This order of events is being unravelled by studying the voltages surrounding the neurons, as this electric field is deemed to be the essence of the signal conveyed by the neuron. These voltages are read using high impedance electrodes implanted in the brain. Shenoy's group has seen a clear distinction between the electrical activity of the neurons in the planning pre-motion period and in the peri-period that includes the conduction of motion.

Professor Krishna Shenoy

An algorithm is needed to enable the prosthetic to read the electrical activity from the neurons at different intervals and to provide it with a procedure to interepret this data. Presently, the algorithm used is the Plan Movement Maximum Likelihood (PMML) which approximates each of the neurons as a point data source representing a Poisson distribution. Statistical analyses of large data sets have been done to attain quantitative results and give the prosthetic a reliable means of interpreting the data from these results.

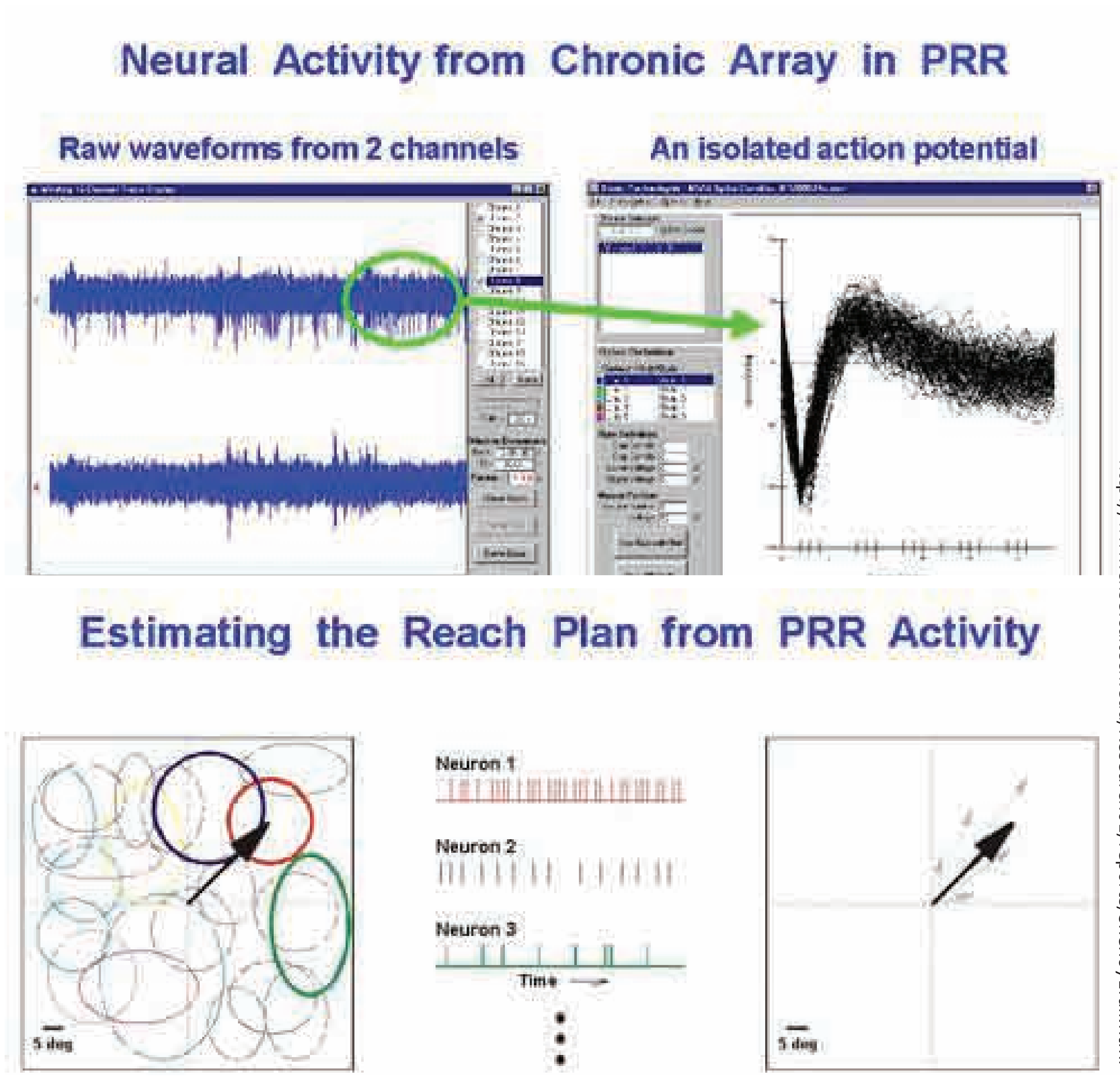
Mimicking the Brain: Early Successes

The work done by Shenoy's group has produced some encouraging results. The algorithm to read the neurons as a whole set has proven very effective, and the group has been able to predict with 90% certainty what the neurons are trying to say in terms of future movement simply by extracting information from 40 random neurons in the chosen region of the brain. The low number of neurons used for effective communication is critical since it minimizes the number of electrodes that have to be inserted into the brain, making the operation less invasive.

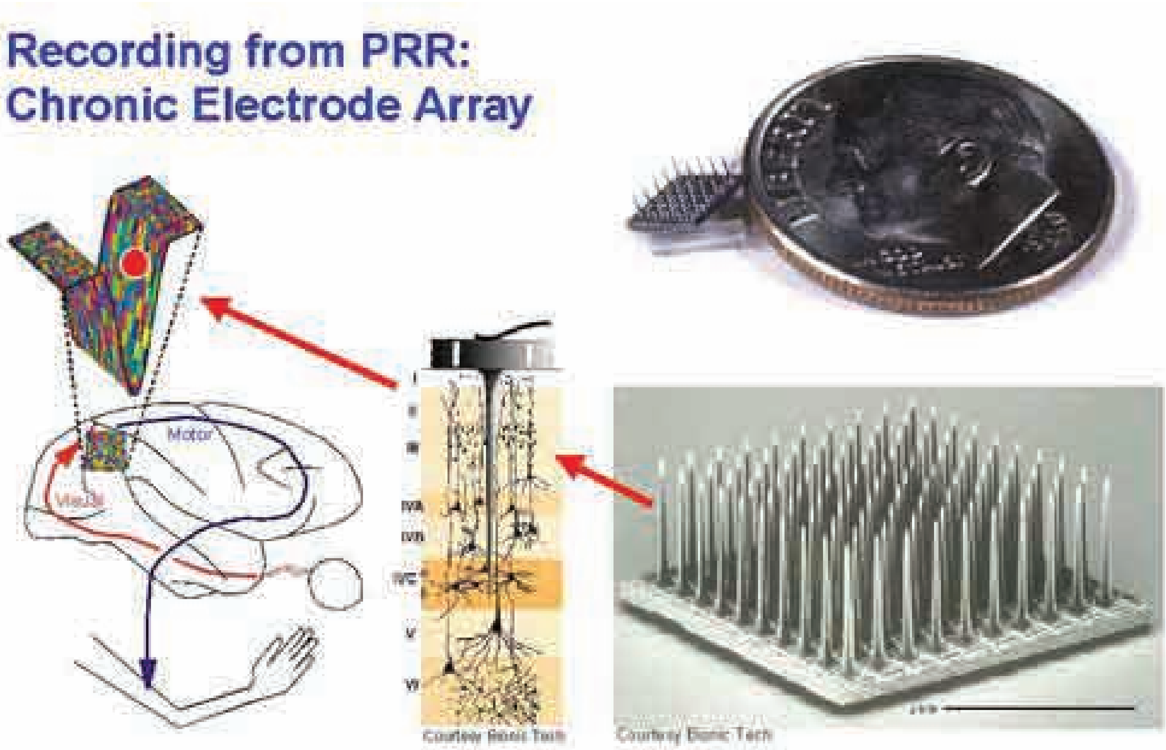
We have already seen many successful results of

(a) The neural activity from a group of neurons is represented and studied in the form of a plot of voltage variations. (b) Statistical analysis of such data helps us judge how the potentials relate to the trajectory and speed of the reach.

(a) (b)



http://www.cnse.caltech.edu/Research01/reports/shenoy1full.html http://www.cnse.caltech.edu/Research01/reports/shenoy1full.html



A structure of the electrode grid implanted into the mind to read signals from neurons.

medical engineering in areas such as cochlear implants, tremor-control devices, and other neural prosthetic systems aimed at delivering signals to the nervous system. These successes are a source of encouragement to the researchers who are intensifying the efforts to take biological signal processing to a new level. What is most groundbreaking about Shenoy's research is that this is the first example of a machine model that predicts cognitive states using neural activity. In previous models, neural decoding algorithms have typically used estimators that do not explicity model internal dynamic states or the transitions between these states. However, the algorithm introduced by Shenoy's group is versatile and can recognize the arrival of rapidly changing motions.

An important consideration is whether the electrical activity under study is effective during neuronal damage causing paralysis. However, since the parietal reach region of the brain relates to our system of vision and is not directly connected to our motor activities, it can continue to provide the necessary information even in the case of neuronal paralysis in other regions. This is of critical importance since it offers hope not only to people who have damaged limbs but also to those who are paralyzed.

What Next?

Shenoy's group still has some work to do before it can claim to have a smoothly working prototype of such a limb. Development is in progress to create an adaptive filter that analyzes neural data with a computation time fast enough to operate in real time, even with hundreds of neurons added at intervals to the data set. This is expected to contribute to the ability of the arm to respond rapidly to the most recent data from the brain.

At present, Shenoy is also attempting to incorporate data from the peri-movement stage into the information system to optimize the trajectory of the arm movement. Extracting electrical information from the same neurons multiple times shows critical trends in the electrical potential planning period relating to the speed of movement and assessed distance, critical to judging the trajectory of the motion. If the trajectory can be optimized, it will minimize jerk, twisting, and torque effects in mechanical motions. This will reduce the response time, since the limb will be capable of picking the path of least time to its target.

With the rapid advances in technology and science, the integration of electrical engineering and neuroscience will one day direct the electrical spark to restore movement to those who are without it. S