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BY ALISSA SWERDLOFF

THE BRAIN BUILDERS

The neuroscientists who designed 2 million brain cells in a computer are making a revolutionary model of the mind and the world.
Eight years ago, a team of brain researchers decided that the best way to explore the function of the body's most complex organ was to try to "grow" a portion of a brain in a computer. That experiment, and the novel theory of brain function it spawned, may revolutionize neuroscience as thoroughly as the theory of relativity revolutionized physics. Scientists have produced plastic hearts and grown muscle cells in petri dishes, but could a simulated portion of the brain be grown in a computer? And would the brain's complex inner workings be better understood as a result? The task was gargantuan. Two years and 2 million computer-generated "brain cells" later, Drs. Rodolfo Llinás and András Pellionisz and their collaborator, Dr. Donald Perkel of Stanford University, succeeded in simulating a cerebellum, the part of the brain responsible for coordinating voluntary movement. When the two New York University Medical Center scientists activated their creation, it

(Far left) Computer image of a Purkinje cell—the cerebellum's most common cell. The branches are dendrites that receive signals from parallel nerve fibers (dots) that they touch. Drs. András Pellionisz (left) and Rodolfo Llinás (above) study the distribution of voltages in the cell.
CEREBELLUM

The human cerebellum is made up of 100 billion nerve cells, the neurons, or as many cells as there are stars in the Milky Way. These cells communicate via a network of a million billion interneuron connections, or synapses.

The central neurons of the cerebellum are slender in one dimension, thick in the other two and are about 400 millionths of a meter in diameter. They look a bit like microscopic trees, with numerous branchlike projections called dendrites that grow from one end of the cell. At the other end, a single branch emanates from the cell’s body. This long central stem, or axon, transmits the signals gathered by the dendrites to other nerve cells.

Each neuron is capable of receiving chemical signals through the synapse and transmitting them electrically along its axon to the synapse at the other end. There the signal is reconverted into packets of chemical messenger that move across to the next cell and trigger it.

Without the cerebellum, animals are unable to perform coordinated movements. Humans who suffer cerebellar damage develop tremors and have difficulty performing the simplest motor tasks, such as touching the nose.

Whereas real brains are made of nerve cells, blood vessels and supporting tissue, computer brains need a different sort of building material. To program neurons into the computer, Pellionisz and Llinás equipped their machine with both a microscope and a TV camera and instructed it to examine and memorize the forms of hundreds of real neurons from various locations in the cerebellum.

The computer recorded the exact shape of each cell: the length of its axon, the number of branches, the interbranch distance, the angles of branching. It compiled information about what a computer-generated nerve cell might look like and compounded the data into a neuron-shaped “probability cloud” that could serve as a template for generating hypothetical neurons.

As instructed by Llinás, Pellionisz and Perkel, the computer then created hundreds of thousands of “neurons,” each slightly different from the next. Governed by the knowledge that certain types of cells occur in certain layers of the cerebellum and that each part of the cerebellum has its parallel neurons oriented in a particular direction, each cell was assigned to an appropriate layer and oriented.

NEURON STIMULATION

To make the computer cerebellum complete, the researchers programmed each neuron with the ability to stimulate any other neuron it touched. Thus, when...
A thinking cap linking the human mind with computers may soon be as common as a pocket calculator.

Current developments in microelectronics and bioengineering have made the coming of these human-computer linkups—or "symbionic minds"—inevitable, according to Dr. Glenn Cartwright, computer scientist and educational psychologist at McGill University. Symbionics is Cartwright's word: symbiontics, plus bionic.

With symbionic minds, we could receive and send electronic signals: turn household appliances on and off by pure thought, retrieving unlimited amounts of information instantaneously, monitoring the body's functions and creating new senses such as the ability to perceive radiation or "see" with radar. Says Cartwright, "Merely thinking of someone you wish to talk with could initiate a search by the symbionic mind to locate that person anywhere in the world and establish direct contact over the telephone network."

Though many scoff at Cartwright's predictions, research seems to suggest that he's right. Advances in prosthetics now enable amputees to manipulate artificial limbs by "thinking them to action." Sensors in the damaged stump, picking up electrical signals from the brain, trigger movement in the limb. When the mind sends a message such as "move the index finger," the prosthesis obeys.

Brain-wave patterns can be used to virtually read minds. Says Cartwright, "There's a science called neurometrics that allows researchers to get a general idea of your thoughts by decoding specific brain-wave patterns. For example, a P-300 wave is usually associated with decision making."

Meanwhile, others have been perfecting pacemakers that, implanted under the scalp, can be triggered by an outside signal to prevent epileptic seizures. With each operation, surgeons gain a greater understanding of how to match up mind with machine.

"People now say the brain is like a living computer," remarks Pellionisz. "Before computers, they said it was like a radio—or a telephone—for whatever was the top technology at the time." In all machines, the sequence of connections is vital. To draw an analogy between brain and machine function, researchers have proposed that the nervous system transmits encoded information along linked chains of nerves to a point in the brain where it is received and "decoded." You see an orange, and its code signal travels down your neural pathways.

The success of the Llinás-Pellionisz simulation mitigates against the brain-as-machine theory. If the brain mimics a machine, its specific wiring pattern would be crucial; an improperly wired computer is

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no computer at all. But the brain simulation demonstrates that parallel neurons can be wired together with a great deal of variation—nothing like a mechanical device. If a machine could work on this principle, the transistors, capacitors and resistors of a stereo could be wired up in a sloppy fashion—and music would flow.

TRIGGERING IMAGES

But if the brain does not work like a machine, how does it work? Based on their simulation, Llinás and Pellionisz propose that information reaches the brain as the result not of a chain of transmission but of the pattern of nerve activity created by hundreds of thousands of parallel fibers firing simultaneously. Because each neuron is slightly different from the next, it experiences its own version of an object or event. Each fiber therefore fires off nerve impulses at its own particular frequency. The pattern of transmission—that is, which cells are firing and at what rate—produces the internal image we call a thought.

The situation is a little like having a large number of witnesses to a car crash. Each viewer sees the event from his own perspective, but the incident can be reconstructed fairly accurately from the consensus of all the witnesses.

Our perception of a jet plane, for example—its size, color, shape, sound, number of engines, etc.—sets off certain neurons at certain rates. The entire array of stimulation means jet to the brain. And since there are millions of neurons, an almost infinite variety of patterns is possible, each corresponding to a unique object or situation in the outside world. Llinás uses the analogy of a color TV screen to demonstrate that the mind routinely resolves discrete signals into the perception of a whole object. A color TV screen is composed of thousands of little dots—some red, some blue, some green, some brighter than others—and each fires differentially from its neighbors. But when you look at the Tonight Show, you don’t see the dots—you see Johnny Carson.

If you hold an apple in your hand, you know its position, size, shape, color, texture, hardness, aroma and temperature simultaneously. These dimensions are perceived all at once and seem to mix together; the experience has a unity to it that we call apple.

In scientific terms, Pellionisz and Llinás would say that every human being has inside his head an “n-dimensional hyperspace,” that is, a nerve network that can accommodate an almost infinite variety of different patterns, each corresponding to unique objects or events in the world. This rather cosmic-sounding entity has given the researchers a tool for organizing the thousands of simultaneous nerve firings that accompany perception.

Einstein postulated a four-dimensional hyperspace, a model of the Universe that consisted of the three dimensions of physical space—length, width and height—plus a fourth, time. But hyperspace can have any number of dimensions above three. Indeed, if time can be considered a dimension, why not redness? Or hardness? Or temperature? Or any of an infinite number of other qualities?

Why not? Probably because we are trapped by our own preconceptions. We have always thought of “dimension” in terms of length, width and height. When we want to graph something, we think of three axes: x (left and right), y (up and down) and z (front and back).

Now, try to free yourself from the constraints of three or even four dimensions. Imagine hundreds, even thousands of axes on the graph paper—one for redness, one for suppleness, one for softness and so on. Along each axis, a particular quality can be described on a scale of 1 through 10. An orange juggler’s ball at the top of its trajectory will have position values—x, y, z—but it will also have values for orangeness (say, 10), hardness (say, 4), temperature (say, 5) and a host of other qualities. Somewhere in n-dimensional hyperspace is a point whose coordinates are these numbers—and that point represents precisely this ball.

In simplified fashion, the concept of a hyperspace—the so-called Tensor Network theory of brain function—works like this: each neuron is considered a dimension, and the number of times it fires is thought of as units along that dimension. Just as the theoretical values associated with a juggler’s ball can be made to correspond to a single point in hyperspace, so too can the neuron-firing values produced by any stimulus.

With a little abstract geometry, the activity in hundreds of thousands of parallel nerve fibers can be reduced to one point, called a vector. An apple would create a unique firing pattern, which would reduce to a different point in n-dimensional space—an “apple” vector. An orange would create an orange vector.

Actions as well as perceptions can be explained in terms of neuron-firing patterns. You want to sneeze and you also want to scratch. The sneeze, of course, takes precedence. According to Llinás and Pellionisz, your choice depends on the fact that the sneeze involves so many neurons firing simultaneously that “it’s almost like a small epileptic discharge.”

By far the most elegant and useful aspect of the hyperspace brain model is that it proposes a method for converting intention into action. Leonardo da Vinci sees Mona Lisa and decides to paint her. But how can he organize the thousands of muscle cells in his arms and hands to reproduce the image of his model? Vectors in brain hyperspace may hold the key.

Vectors are geometrical entities that can be mathematically translated from one frame of reference to another. The process is called transformation. Llinás and Pellionisz feel that the brain may be adept at such calculation and could readily transform Leonardo’s perception vectors into the action vectors required to paint the portrait. Signals come in, forming the brain of Mona Lisa’s appearance; signals go out, telling the joints and muscles of Leonardo’s arm and hand how to reproduce her face.

But does the brain actually read nerve-firing patterns and translate them into action? The best test of the theory would be to record real nerve impulses in hundreds of fibers entering the cerebellum and then record the impulses in another set of nerve cells leaving the cerebellum. The computer could then combine these values so that a mathematician could tell whether the outgoing signals represented a transformed version of the incoming data. Here, unfortunately, we are approaching the limits of modern technology: Pellionisz and Llinás have already completed designs for a device capable of simultaneously recording large numbers of individual neurons, but for the moment, theory has outrun the possibility of experimental validation.

Undoubtedly, the proof (or disproof) will come someday. If this new model of brain function is validated, it will be of interest to philosophers as well as scientists. We may have to alter the way we view ourselves, our consciousness—our very being.

INTERNAL UNIVERSE

According to Llinás, the ability to close our eyes and construct a perfect image of an orange suggests the existence of an internal universe. We create at will the firing pattern that means orange.

In fact, the two scientists feel that we may be born with a tentative model of the world already programmed into our brains. Other animals, they note, seem to be wired to recognize those structures of the Universe that will be important for their survival. The nerve-firing patterns caused by various objects—apples, oranges or sports cars—merely “turn on” the appropriate portions of the internal world. In a strict sense, no fundamental information passes into the brain, and
“very deeply, we learn only what we already know,” says Llinás.

At least some of man’s knowledge and ability is probably preprogrammed as well. Human infants are born with the ability to pronounce all phonemes, the sound components of language. They can even pronounce the phonemes of languages foreign to their place of birth. German babies can easily pronounce the th sound of English, and English infants can pronounce the rolled r of Spanish. (A child starts to lose this ability at about six months, when it begins to specialize in a particular language.)

PERCEPTUAL WIRING

How extensive is this innate wiring? It depends on the creature. A chick’s perceptual abilities are largely predetermined, with some small ability to learn. Human preprogramming is much less extensive—but we seem to be wired to some extent. Says Llinás: “You will recognize those patterns that form part of your perceptual library; you will recognize the colors that you have evolved to be able to recognize.”

We utilize this inner universe to great advantage. By mentally mobilizing our “props,” we can monitor or experiment with behavior and predict the outcome of our actions. As Llinás puts it: “You hunt your bear many times before actually trying it on the outside. In this way you can find out what you need. You can even project yourself into the bear .... The hunter can become his prey.” The brain is a most versatile part of man.

But is the brain simply a part of man? Or is man, perhaps, part of the brain? If the brain contains a model of the Universe, then in a sense it must be far more than the self. The I is only one pattern that the brain generates.

The I is an important pattern, no doubt. In order to survive, you know that you are a particular kind of beast with particular competitors and certain nutritional needs. Nevertheless, the I disappears when you sleep—but the brain hums on. It is busy producing the many other patterns of which the conscious I is unaware, patterns that lie outside the small portion of reality we inhabit on this Earth.

Ironically, the metaphysical speculation that grew out of the computer cerebellum experiment suggests that a full computer brain may be an impossibility. A computer can utilize only the information that man can arrange to have programmed in.

According to Llinás, we are the music that the brain’s instruments, the neurons, create. Each neuron plays its own notes, and together they play the tune called man. When they die, we die. Even in life, they do not always perform the symphony of consciousness. At night we dream, and they move on to other songs.