Growing 'Brains' in a Computer

Computer models of the brain's 'wetware' are beginning to boost our understanding of how a tangled mass of cells and fibers can see

By IVAN AMATO

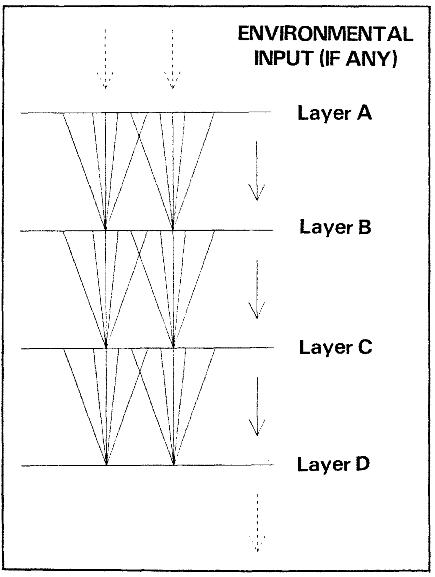
Your muscles contort and the bed sheets fly in response to the loud, electronic tones coming from your alarm clock. It is seven in the morning and time to get on with another day. After denying an internal request to resume sleeping, you snap open your eyelids to kickstart your visual system. Following a blurry instant, darks, lights and lines and boundaries appear. You recognize this particular arrangement of features as your bedroom.

Brain theorists and experimentalists are learning more and more about the ability of living things to detect and respond to environmental features. Building on this ever-growing foundation, they increasingly are able to inspire, test and help follow up each other's ideas about how the brain works.

Now, researchers are drawing from what is known about the nervous system to build computer models, and sometimes even computer hardware, of neural systems such as the visual system, olfactory cortex and cerebellum. Some researchers are using a new breed of "massively parallel" supercomputers (SN: 1/10/87, p.28). Not only do the electronic versions of neural systems behave somewhat like their biological brethren, but they also empower the scientific imagination to screen theories about how the brain works, how it develops and how it directs bodily responses. And this greatly enhances the ability of the experimentalist (often the theorist wearing a different hat) to ask the right questions about the brain before risking many years, dollars and animals in the effort to get answers.

Starting with a few biologically plausible rules that govern how cells in a network are connected and how those connections change and develop, brain scientist Ralph Linsker of the IBM Thomas J. Watson Research Center in Yorktown Heights, N.Y., wanted to know if the network develops any structural properties that turn out to be biologically important. The answer, which unfolded over the course of three papers published separately in October and November issues of Proceedings of the National Academy of Sciences, is a resounding "yes." Linsker models a self-developing, multilayered network that is strikingly similar to that observed in the first few stages of the mammalian visual system.

"There is a lot of impressive biological organization that is present at the birth of the animal," remarks Linsker. To learn about specific developmental strategies, he models the visual system as a "layered self-adaptive network." Each layer is composed of hundreds to thousands of "cells," each of which can receive hundreds of inputs, mostly from its closely overlying cells. How rapidly a cell fires depends on the collective "vote" of all incoming excitatory and inhibitory connections it has with cells on the overlying layer.



Courtesy: Linsker

Schematic of Linsker's model. Each layer contains many cells, all of which receive inputs from an overlying neighborhood of cells of the previous layer. Shown are input "arborizations" for two cells each in layers B, C and D. The dotted arrow at the bottom indicates further layers.

"The firing rate of each cell of the previous layer is weighted, or multiplied, by a 'connection strength,' which can be a positive number for excitatory connections, or a negative one for inhibitory connections," Linsker explains. When the sum of these weighted contributions is large, the receiving cell fires rapidly. Otherwise, the cell is relatively quiet.

Linsker sets his seven-layered network in motion with "random, spontaneous" activity in the first layer and by randomly assigning to the intercellular connections values that correspond to how strongly excitatory or inhibitory each connection is initially. "The layer can develop in several different ways, depending upon these parameter values," Linsker says. He likens this to "the possibility that evolution may 'make' analogous choices that govern the development of layers of cells in biological systems."

In an effort to understand how feature-analyzing cells might form before birth in macaque monkeys and other mammals, Linsker built into his model a development rule: If the firing of a cell in one layer is usually preceded by the firing of a cell in the previous layer to which it is connected, the strength or efficacy of that connection increases. Its vote as to what the receiving cell does gets stronger. If not, the connection strength decreases and its vote becomes less influential.

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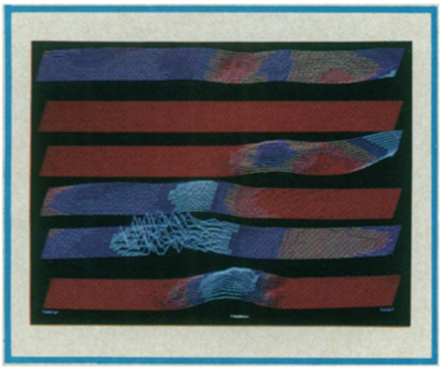
In Linsker's model, seven or more cell layers mature one at a time. Before long, cells begin to emerge with biologically significant properties. As the cells in layer A fire randomly, their synapses, or connections, with cells in layer B reach their maximum excitatory or inhibitory states. If initial conditions are such that layer B develops into an all-excitatory layer, then cells in layer C of the model develop features much like specialized cells of the visual system called spatial opponent cells, which scientists identified long ago in the retina and in the brain.

These cells amplify any contrast between signals received by closely spaced sense cells, such as neighborhoods of photoreceptors in the eye. This is represented in the model by the distribution of excitatory and inhibitory synapses on the cell bodies in the third layer.

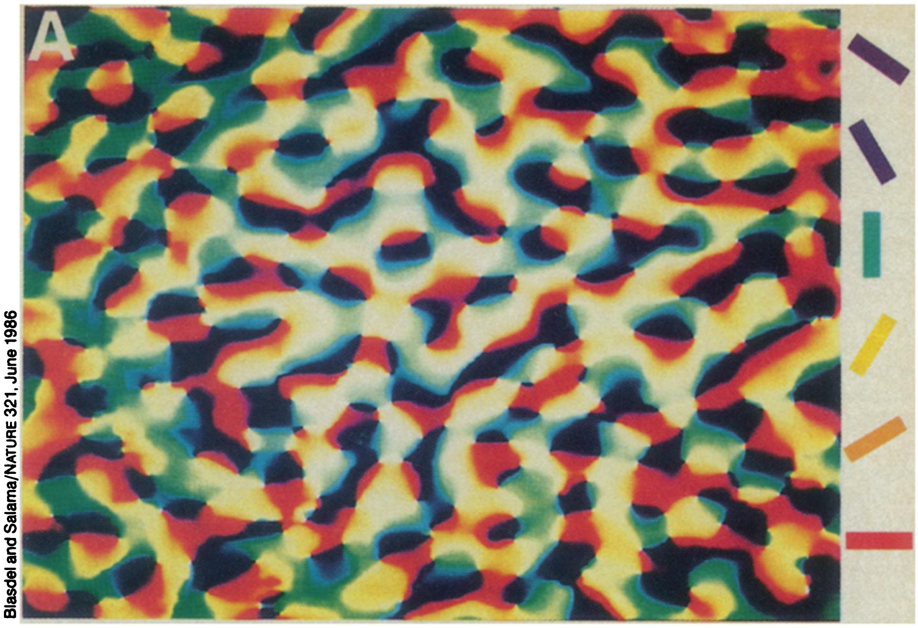
After a few more layers of the model mature, each time showing more pronounced spatial opponency properties, a new category of cells emerges. These "orientation selective" cells in the model have characteristics that closely resemble cells of the nervous system (described in the 1960s by neurophysiologists David H. Hubel and Torsten N. Wiesel) that respond to edges or to bar-shaped environmental features with different orientations – vertical, horizontal, oblique – in space.

In addition, when Linsker added to his model lateral connections between the cells of this layer, the *pattern* of orientation selectivity of these cells developed in ways that are similar to the patterns found in experiments on macaque monkeys, reported in the June 5 NATURE by Gary G. Blasdel and Guy Salama of the University of Pittsburgh.



James Bower and Matt Wilson

A frame from an animation of simulated piriform (olfactory) cortex activity. Each layer represents the spatial distribution of electric potential at different distances below the surface of the cortex (top layer is at the surface). The potential at each point in the cortex is represented by the color and deformation of the surface at that point. This particular frame represents activity 52 milliseconds after activation of the cortex and allows the modeler to see patterns generated by the complex interconnections among the 1,000 modeled neurons.



Blasdel and Salama/NATURE 321, June 1986

A photo of a monkey visual cortex in which the colors represent the orientation selectivity of the neurons in this brain region. This experimentally derived map of orientation cells has some features strikingly similar to the theoretical map of such cells that emerged in Linsker's model (see cover).

"This sort of analysis might provide us with information so that we can understand how neurons develop to have the types of connections that they do," Linsker suggests. And it is the physical properties and connections of neurons that largely determine what features of the world they are most apt to detect.

Until now, neuroscientists primarily have been describing what brain cells are like – what they look like, how they are placed in relation to other cells, how they are connected. Presumably all of these "whats" and "hows" have something to do with cognitive abilities. In a presentation at the recent meeting of the Society for Neuroscience, Linsker commented that "despite the complexity of biological development processes, [his work] may have succeeded in isolating some of the key features responsible for the development of neural architectures for perception." As more predictions come from the model, Linsker says there will be more opportunities to test this possibility.

Many other scientists are modeling neural networks, also with encouraging results. Biophysicist Terrence Sejnowski of the Johns Hopkins University in Baltimore and Princeton (N.J.) University psychologist Charles R. Rosenberg are modeling a 900-cell neural network that is teaching itself to read and pronounce sentences. Biochemist John J. Hopfield of Caltech in Pasadena and David Tank of AT&T Bell Laboratories in Murray Hill, N.J., use a parallel processing computer to quickly solve such puzzles as the Traveling Salesman Problem: What is the shortest route a salesman can take to visit each of, say, a dozen cities? And at the University of California at San Diego, philosopher and theoretical biologist Paul Churchland has modeled the superior colliculus, a brain region involved in such feats as grabbing a glass of water.

James Bower, also at Caltech, and his colleagues have drawn on massive amounts of literature and on Bower's own neurophysiological experiments to build computer models of mammalian olfactory and cerebellar cortices. "We're convinced that the simulations are accurate," Bower told SCIENCE NEWS. His group will use the Mark IIIe Hypercube concurrent computer, whose architecture resembles actual neural architecture far more than does that of conventional serial computers.

"We do detailed biophysical studies . . . , which provide information for the modeling," Bower adds, "and we do multicell recording [with electrodes] in brains to test the predictions of the model."

The emergence of spatial opponent cells or orientation selective cells from a self-developing network as in Linsker's model, and the simulation of 100,000 interconnected neurons active inside the Mark IIIe Hypercube, as Bower hopes to have soon, are achievements that might catapult computers closer to the class of object called brains, albeit electronic brains. Although experiments with biological systems will remain the final test for theories of neural action and development, these new models will provide brain scientists with a powerful way to screen many more ideas far more quickly and less expensively than before. And at the same time, neuroscientists and computer builders will come closer to breathing reality into computers that think and function the way they do. □