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Chips ape net-centric model of human brain

By Chappell Brown
EE Times
(09/20/00, 1:08 p.m. EDT)

BALTIMORE — A researcher at Johns Hopkins University is using a collection of VLSI chips to confirm new insights into how the neocortex of the human brain unites information from the senses to create a coherent picture of the world. Andreas Andreou of the university's Department of Computer Science and Electrical Engineering has wired the chips together with optoelectronic connections to build an image-processing module modeled on Boston University neural theorist Stephen Grossberg's latest insights into brain function.

Grossberg recently proposed what might be described as a "net-centric" view of brain operation in which the communication channels between the brain's processing modules perform a crucial blending of different perceptual units. This view is essentially different from the conventional model that likens brain operation to parallel processors found in digital computers or analog distributed processing networks. Andreou is convinced that the shift in emphasis from processor to network holds the key to solving some of the difficult problems facing computer scientists.

"Despite the phenomenal success in engineering rudimentary ears, eyes and noses for computers, our progress has not generalized to more complex systems and harder tasks," Andreou said in a presentation at the recent Critical Technologies for the Future of Computing conference, held last month in San Diego. It is at the neocortex level of information processing, where sensed information is assembled into a full picture, that current technology seems to run into a brick wall.

Grossberg's analysis of how the neocortex, a thin layer at the front of the brain, integrates sensor information may hold some hope for cracking the really hard problems faced by computer scientists. "In engineering terms, this view suggests that neural information processing is perhaps better abstracted by architectures that resemble communication networks rather than

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traditional computers," Andreou said.

A lot has been learned about how the eye extracts basic features such as object boundaries from images projected on the retina, but supposedly autonomous robots using the latest image sensors and imaging algorithms do a very poor job of navigating around the various objects in a room. Similarly, speech-recognition systems require a quiet room and some coaching from individual users in order to work well. In contrast, the brain is able to decode the meaning of speech in noisy environments that obliterate most phonic information.

Progress in understanding how the ear, eye and nose process information is tied to the obvious purpose of a given sensory organ. Knowing what the neural networks in the human eye are attempting to do eliminates a lot of variables from an analysis of their operation. That knowledge can then be further verified by building electronic models in the form of silicon retinas that are able to process images.

Once information is preprocessed in the outer networks of a person's senses, the signals converge on the neocortex where, by some mysterious process that runs at real-time speed, the information is integrated into what human beings experience as the world. It becomes much more difficult to pick out a simple component of this area and decide what function it is performing.

Connectivity contrast

One physical fact that makes this task insurmountable is the high degree of connectivity in the brain's networks. That is also a barrier to the electronic modeling of the brain, since silicon-based circuits have very low fan-out in comparison. In addition, the ability of the brain to blend highly diverse types of information into a coherent whole is something of a puzzle. Current digital computers and sensor algorithms seem to lack much of the brain's flexibility and power at this task.

Andreou is attempting to get around the interconnection barrier by using optical interconnects. The wide bandwidth of optical channels essentially multiplex signals in a way that models the complex interconnections. Physically, the neocortex is organized into six two-dimensional layers that are highly interconnected. The layers are then connected vertically by columnar structures, each of which has about 100 neurons. Andreou's image-recognition system implements that basic physical model by using analog ASICs to represent the two-dimensional layers, and by using optical interconnects to multiplex the interlayer connections.

The architecture implements a "laminar computing" model that explains how low-precision analog computations can be assembled into more stable coherent models of perception that are still flexible enough to learn and reorganize as more information arrives from the environment. A joint project with Grossberg's Boston University research group has developed a standardized optical interconnect system called "address event representation," which is able to encode analog signals as binary pulses. These pulses are modeled on the voltage spikes output by neurons. The system also specifies certain design parameters for the analog silicon chips so that different ASICs can be plugged into the same optical interconnect modules.

The location of neurons and the time of firing constitute the basic address-event code. Communication processors route and blend these basic code units to model a given neural network. This approach makes it possible to represent and emulate complex spatially organized networks via multiplexing on relatively few wide-bandwidth optical interconnects.

Circles and squares

The electronic/optical analog architecture is providing the researchers with a model system aimed at pinning down exactly what the networks in the brain's cortex are doing. It is here that Grossberg has attacked the problem from both the basic network level and at the perceptual level. Important clues can be deduced from well-known perceptual experiments. One of the simplest is the "Kanisza square," which is simply four small solid-colored circles placed at the corners of a square, with the inward-facing quarters of the circles removed. The boundary of a square is not drawn, but when this figure is viewed, a square shape clearly emerges from the drawing. Not only does the brain generate the square image, it also "fills in" the square with a higher-intensity version of the background color.

The filling-in illusion also occurs if the square areas, instead of being removed, are given a different color than the rest of the circle. In this case, the cortex's perceptual system will fill in the blank area with the color, and the viewer will see an illusory colored square.

The interesting information-processing paradox in this experience, which anyone will have when viewing the figure, is that the square shape is clearly not detected by the eye itself, which is specifically designed to detect actual boundaries in an image. Instead, it is put together at a later stage in the neocortex networks. It appears that the brain processes the image as both a boundary and a colored surface. But before the boundary computation is complete, the brain begins to fill in the surface characteristics. In this case, a square emerges from the process, even though the eye does not actually see it or pass that information on to the cortex.

There are many variations on this simple phenomenon that cognitive scientists have created to demonstrate aspects of visual processing. This type of effect poses a serious problem for the conventional model of a computer composed of a set of modules, each devoted to a specific task. A computer's image-recognition algorithm designed to detect and assemble boundaries in an image would process the four circle shapes with square corners, but could not generate the square.

Grossberg's theory is that the neocortex does have specific processing modules, but these individual processors only compute partially complete results. The partial information is then blended into a whole via complementary information channels in the brain's dense interconnections. Generally, perception is tackled by the brain through pairs of complementary features. For example, the boundary of an object is complemented by its surface, or color is complemented by brightness. A network model explains how the brain is able to partially process a pair of complementary qualities and then blend the results together, passing the partial result to another processing stage. After several of these individual processing and blending operations, a complete picture emerges.

The theory shows how a model of specific processing modules can produce a highly flexible and interactive perceptual system. The theory is supported by actual neural-network models taken from the physical organization of the neocortex. Andreou and other researchers applying these models to sensor processing systems are finding that the same basic models can be applied to diverse problems.

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