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TECHNOLOGY ASSESSMENT OF NEURAL NETWORKS

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An assessment of the current, near-term (1995), and long-term (2010) trends in Neural Networks is given.

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s/ John W. Gowens
Division Chief
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s/ John R. Mitchell
Director
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NEURAL NETWORKS

1. HISTORICAL REVIEW

A construct which is called a "neural network", a "neuromorphic system", a "connectionist", or an "organic-like design", which has been set aside for nearly two decades, is now becoming one of the most crucial emerging technology topics. Tactical Technology Office of the U.S. Defense Advanced Research Projects Agency (DARPA/TTO) labels this technology "as important as the atom bomb". DARPA has announced a proposed $390 million neural network program at the International Conference on Neural Networks in San Diego, California, July 1988 (1).

Unlike a Von Neumann type of computer which needs to be programmed to carry out an information-processing function, neural networks are promised as an alternative to artificial intelligence (AI) to attack many problems AI has been unable to do such as seeing, speaking, reading, and learning from experience. While conventional digital computers process detailed steps of a stored program to carry out its goal, neural nets can be adaptive or trainable through a series of trials to learn how to process information.

The philosophy behind neural networks is to try to build computers that work as the way the human brain does. Researchers began to devise models for the structure of the brain in the 1940s. Frank Rosenblatt, a scientist at Cornell University, built a simple neurocomputer in 1957 with eight processing elements (PE) called Perceptron that could perform typed-character recognition. Professor Stephan Grossberg, Boston University, made significant progress by incorporating mathematical representation with neurobiology. For years, computer researchers have been trying to create machines modeled on the human brain while ignoring the complex details of the brain's anatomy. These early neural networks were unable to handle many situations. The research was abandoned until John Hopfield published his work in 1982 and characterized the neural networks as feedback circuits and energy functions.

Today with better understanding about how the human brain works, the researchers have made tremendous progress with such accomplishments as multi-layer systems, advancements in mathematical theories, and increased understanding of neurobiology to form a bridge between the biologically-oriented neural modelers and the artificial neural network modelers. The first commercial neurocomputer was developed in 1985 by TRW's AI Research Center in San Diego. In 1986, Terry Sejnowsky proved that a neural network could learn the speech patterns of a 6-year-old child (2). Today the number of firms and institutions involved in some form of neural research is about 100, and at least 78 applications have been developed in the areas such as vision, signal processing, classification, robotics, speech, and sensor fusion (3). Even though the neural network is still in its infancy, it offers the prospect of saving substantial amounts of time and human effort. However, there are many factors to be considered, including:

- The required training time for scaled up neural networks approaching the capacity of the human brain.

- The high cost, low density, and low speed of current devices as limitations of current technologies.

2. CURRENTLY AVAILABLE

2.1 Brain and Its Applications to Neural Networks

2.1.1 Brain Model

The human cerebral cortex is a massive parallel processor, consisting of about 100 billion neurons, or nerve cells. Each neuron has roughly 1,000 dendrites, which receive electrochemical impulses from sensory organs or other neurons by means of a specialized contact called a synapse. The human nervous system contains about 100,000 billion synapses. If the system operates at 100 Hz, it functions at about 10,000 trillion interconnections per second. Each nerve cell has an axon that sends the nerve impulse on to other neurons.

Current psychological theory contends that logical and rational operations are located on the left hemisphere of the brain, while creative and intuitive operations are on the right hemisphere. Neurocomputers are modeled on the way the right hemisphere processes.

2.1.2 Neural Networks

A neural network consists of a collection of processing elements, corresponding to nerve cells. Each processing element consists of several operational amplifiers and resistors with a small amount of local memory and processing power, several inputs analogous to dendrites, and one output anologous to a neuron's axon. A variable resistor representing the synapse is a connection between the output and input(s) of processing elements. When a PE receives an input signal that exceeds a preset threshold, it sends an impulse signal to others, i.e., it fires. The input signal, called weight, is the sum of its inputs (dendrites). The set of weights provides a self-adapting dynamic system that can modify its response to each input pattern. This determines the strength of the connections between PEs and helps the system identify features encountered in the past, and, therefore, the system can provide the correct output for each input applied after a number of trials.

How to build a neural network is mainly dependent upon how the elements are connected. There are several possibilities such as feed forward, feedback loops, fully connected, sparsely connected, or random connections. The nature of the connections depends on the model, or architecture, used to construct the neural network. The PEs are connected into several layers. One layer receives inputs from the layer above and provides output to the layer below it. Since weighted inputs can change over time, the network can adapt and learn.

There are three basic methods used to train a neural network (3):

- Supervised training: This training requires an external teacher to provide an error signal when the network provides an incorrect response in order to teach the network the correct response until it can consistently produce the correct response.

- Unsupervised training: This training requires no external teacher.

- Self-supervised training: An error signal is generated by the system until it produces the correct response.

2.2 NEURAL NETWORKS APPLICATIONS

Neural networks vary considerably. At least 50 different types and 78 applications have been developed from the Perceptron by Rosenblatt (1957) to the Boltzmann and Cauchy machines by Hinton, Sejnowsky, and Szu (1986). The number of processing elements range from eight to one million, the number of connections from 512 to 1.5 million, and the number of connections per second from one thousand to several million. These networks exhibit a variety of capabilities from typed-character recognition to pattern recognition for images, sonar readouts, and radar.

The development areas and applications are classified as follows (3):

- Vision: Image classifier, target recognizer
- Speech: Net talk, word recognizer
- Classification: Risk analysis
- Signal processing: Sonar classifier, target tracking, adaptive channel equalizer, process monitor
- Robotics: Forklift
- Sensor Fusion: image fusion

And the following applications have been fielded:

- Risk Analysis System
- Process Monitor
- Word Recognizer
- Adaptive Channel Equalizer

2.3 Hardware/Performance

2.3.1 Micro-electronics

To build a network that has the physical characteristics and construction like the human brain is impossible with current technology. However, computer builders are looking to construct devices consisting of large numbers of PEs that behave as much like the brain as possible.

Developers including Hecht-Nielsen Neurocomputer Corp., IBM Corp., Science Applications International Corp., Texas Instruments Corp., and TRW Inc. have introduced neurocomputers, the hardware on which neural networks can be implemented. These are coprocessor boards that plug into conventional machines to process immense quantities of information (4).

Carver Mead' s artificial retina is a single chip containing 100,000 transitors designed to mimic the functions of a biological retina's layers of cells, with 10,000 interconnects and 100 million interconnects per second. Although it does not solve "the vision problem", it can effectively imitate many functions that take place in the living retina (5).

Several other technologies which are expanding hardware capabilities beyond their current limits include Gallium Arsenide(GaAs) and special-purpose charge-coupled devices (CCD). Multiprocessing will improve simulation speed by an order of magnitude.

2.3.2 Optics

Optics is the least mature of all the technologies that are essential to neural network research. However, it will be an alternative when other technologies reach their ultimate limits. The advantage of photons over electrons in networks is that the number of channels can be very large and close together without interference experienced with electrons, and the light source can broadcast to millions of points. The optical technology can offer a very high interconnection level due to its three-dimensional nature. The development of the spatial light modulator (SLM) is critical to neural networks. SLM as a transducer converts a two-dimensional pattern of light into a spatial pattern that can vary its brightness. SLM can perform logic operations, clocking, and can be viewed as a matrix-vector multiplier (6).

2.4 Application to IMA

2.4.1 Information

Even though neural networks can be applied to variety of tasks and problems, the Defense Department has been the principle organization supporting financially the research and development for this field. DARPA, through its Advanced Stragic Computing Program, is funding efforts at Texas Instruments, AT&T, IBM, Bendix, TRW, and General Electric. Most studies, therefore, concentrate more on applications related to national defense. These applications involve electronic information gathering and very high bandwidth sensors in order to help process information in real time. However, these technologies must continue to mature and will take several years of implementation and improvement before being fielded.

There are several areas that neural network technologies can help to improve information processing, such as parallel processing, which will drastically reduce processing time and simplify the algorithm development to save time and human effort.

2.4.2 Networks

Neural network technologies will help in the improvement of network and communications signal processing, load balancing, and multi-processing. The Adaptive Channel Equalizer is now used in virtually all long-distance telephone systems to stabilize voice signals.

3. NEAR TERM

3.1 Neural Network Capabilities

It is expected that within the next seven years (up to 1995) there will be many applications in this field to be fielded into military and commercial world, when the new hardware technologies have been developed to push their capabilities beyond their present speed and storage limitations. While waiting for the hardware development, many developers continue working with software emulations of neural networks that can be used on traditional computers.

The applications of Image Classifier and Target Recognizer will help the strategic defense in information gathering by using electro-optical surveillance. The applications of Sonar Classifier, Target Tracking, Process Monitor, and Image Fusion will help identify a target whether it is friend or foe.

3.2 Hardware/Performance

By the mid-1990's, it is predicted that a network can be built with 10 billion interconnects and 1000 billion interconnects per second. To achieve this essential hardware requirement, the developing technology of Analog Very Large Scale Integration will mature to offer a high density of interconnects. The advanced development of GaAs and CCD will help to boost the technology to meet the expectation. Last but not least, optical technology, which has not been fully developed, will offer a very high density of interconnection due to its three-dimensional nature.

3.3 Application to IMA

Without a doubt the developments in the neural network field will help increase the power of information processing, largely in the areas of communications when transmission speeds are pushed to 10 billion bits per second, and of information when memory is capable of handling 100 billion bits of information. During war time the needs for data gathering, processing, integration, and analysis in real time, or even to offer suggestions as alternatives in decision making will be urgent and vital to the defense. Hopefully, neural networks will provide these services within the next decade.

4. LONG TERM

4.1 Neural Network Capabilities

When the development of vision, speech, signal processing, and sensor fusion technology is mature, the applications of these technologies will be integrated so that a neural network can function as close to the brain as possible. Just imagine that while a person is driving a car, his mind is wondering about what he plans to do for the coming weekend. In the meantime, he is still aware that he needs to speed up to get home for dinner because of his empty stomach, and is still aware that the traffic is slowing down for some reason. How to build a machine to combine and coordinate all the functions that the brain can do is still impossible until the biological scientists understand how and why the brain works.

4.2 Hardware/Performance

To build a network with 100 trillion processing elements and 10,000 trillion interconnections per second is not impossible in the next two decades.

To meet these hardware requirements, it will be necessary to invest more in the development of wafer scale integration and optics technologies. Can a working model of the brain which functions as the brain be built one day? Whether such a model will become true or not remains to be seen.

APPENDICES

A. GLOSSARY/ACRONYM LIST

AI Artificial Intelligence

CCD Charge-Coupled Device

DARPA/TTO Defense Advanced Research Projects Agency/Tactical Technology Office

PE Processing Element

SLM Spatial Light Modulator

B. DEFINITION OF TERMS

Axon: In biological systems, the appendage of the neuron that transmits electrochemical signals away from the cell.

Cerebral Cortex: Major part of the human brain (cerebrum), the surface layer of gray matter that functions mainly in coordination of higher nervous activity.

Dendrites: Branching treelike figure attached to the cell, receive signals from other neurons.

Layers (or "slabs"): Processing elements are arranged as layers in the neural networks.

Processing Element: The so-called artificial neuron that consists of several resistors and operational amplifiers and has a small amount of local memory and processing power.

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