# Applications of Neural Networks in Optics

**Suganda Jutamulia,** MEMBER SPIE
Photonics Research
38730 Lexington Street 274
Fremont, California 94536
    and
University of Northern California
Department of Biomedical Engineering
101 South San Antonio Road
Petaluma, California 94952

**Francis T. S. Yu,** FELLOW SPIE
The Pennsylvania State University
Department of Electrical Engineering
University Park, Pennsylvania
16802

**Toshimitsu Asakura,** FELLOW SPIE
Hokkaido University
Research Institute for Electronic Science
Sapporo, Hokkaido 060
Japan

Attempts have been made to apply the information processing principles of the human brain in order to build artificial neural networks for solving complex problems, whose solutions may require human intelligence. The progress in neurobiology has brought forth mathematical models of neural behavior. This idea dates back to the early 1940s, when McCulloch and Pitts introduced the first mathematical model of a neuron. However, the study on neural networks was conducted by only a limited number of researchers until the early 1980s, when Hopfield introduced his influential paper on associative memory and neural networks. Along with a fast growing interest in neural networks in the 1980s, Psaltis and Farhat introduced the first idea of optical implementation for the Hopfield net.

A neural network can be envisioned simply as a data processing system that correctly maps a group of input data into their specific output data one at a time. A neural network consists of a large number of tightly connected but very simple processors, which are neurons. As a result of massive parallelism, an enormous computational power can be realized. An interesting and useful property of a neural network is the ability to learn from sample or training data. Thus, it is not necessary to write a complex and complete program that might be very difficult if not impossible to write. The data processing system will be ready for use after simply training it with training data.

It has been realized that optics can be of particular value when building massively parallel artificial neural networks. First, the signal is carried by light that has the highest speed of signal propagation. Second, light beams that carry signals may cross without interfering with one another. Third, an optical system is inherently parallel as shown in imaging by lenses and holography. It is anticipated that the evolution of neural network hardware will follow the path from personal computer and workstation to general purpose digital neural computer, then special purpose digital neural hardware, analog chips, and finally to optical hardware. The main disadvantage of optics is that pure optical devices cannot perform nonlinear operation, which is crucial to a neural network.

This special section basically covers two areas. The first area is optical neural networks that attempt to build neural networks partially using optics. The second area is neural network image processing that utilizes neural network algorithms and a computer to process an image or optical data. The desired information of an image may be embedded in other unwanted information. When the separation of the desired information from the unwanted information is not well understood, the neural network algorithm is a powerful tool, since no specific deterministic program is required. Many problems concerning information processing from a detected image can be solved using neural network algorithms. Since the size and the number

of layers of those neural networks are small, a personal computer is sufficient to run the neural network software without waiting for optical neural networks to become available.

Although it is naive to believe that using a neural network large enough with the right learning algorithm will be sufficient to solve any problem, papers in this special section demonstrate some successful and potential applications of neural network algorithms with reasonable network sizes for solving various optical problems either using optics or a digital computer.

The paper by Lu et al. describes a hybrid optical electronic neural network system using a volume hologram. The authors demonstrate their working neural network systems that are packaged in an attache case and a compact lunch box. Zhang et al. demonstrate a hybrid neuroprocessor with 1024 neurons using optical bipolar interconnections and a personal computer. Wen, Yeh, and Yang propose an associative memory model consisting of two layers. The first layer is a modified Hamming net. This model is suitable for optical implementation with currently available optoelectronic devices. Lin and Otsubo propose an optical neural network with a terminal attractor model. The terminal attractors can avoid spurious states of the energy function in a Hopfield net. A holographic associative memory using a phase conjugate mirror as a nonlinear and gain element is demonstrated by Sun et al.

Kinser and Johnson propose an optical system to perform operations of a pulsed coupled neural network. The advantage of this network is that it extracts portions of the input information with each iteration and presents primitive information of the input at different iterations. A joint transform correlator based nearest neighbor classifier is proposed by Lu and Yu. The proposed system improves significantly the light efficiency and the pattern discrimination ability. Mikaelian, Ivanov, and Kiselyov describe a neural network algorithm and its optoelectronic implementation capable of selecting simple features of contour figures. Matoba, Itoh, and Ichioka demonstrate a refined method for fabricating photorefractive waveguides in a lithium niobate crystal. The fabricated photorefractive waveguides are used as adaptive interconnections in optical neural networks.

Sardy and Ibrahim demonstrate the application of adaptive resonance theory and Kohonen's self-organizing map to image inspection using an inexpensive personal computer. Wen, Yeh, and Yang propose a novel fuzzy neural network model for invariant pattern recognition that combines the fuzzy set and a neural network. Tu and Huang report their work on neural network processing of optical signals from a fiber optic sensing array embedded in a structure. Asano, Yamashita, and Yokozeki propose an optimum method of the mathematical morphological filter with gray scale elements. The method can perform neural network learning and morphological operation. Sygnowski and Macukow propose a new method for image compression that is a combination of Kohonen's self-organizing map and Grossberg's outstar structure. Finally, Li et al. analyze the performance of quantized composite filters that are synthesized based on simulated annealing.

We hope that this special section will be a useful reference in this crossed field of optics and neural network theories. We are thankful to the authors who contributed to this special section. We also would like to express our appreciation to the many reviewers who took the time to read and to provide critical comments on the papers. Finally, we are most grateful to Professor Brian J. Thompson who gave us the opportunity to organize this special section. We also thank the editorial staff of *Optical Engineering* for preparing this special section.

**Suganda Jutamulia** received the PhD degree in electronic engineering from Hokkaido University, Japan, in 1985. He completed his BS degree in physics at the Institute of Technology, Bandung, in 1977 and his MS degree in optoelectronics at the University of Indonesia in 1979. He was a research associate and an instructor in the electrical engineering department at The Pennsylvania State University from April 1985 to June 1988. He was a senior scientist with Quantex Corporation, Rockville, Maryland, from June 1988 to March 1991. He was the manager of product development and then the general manager of research and development at Kowa Company Ltd., San Jose, California, from April 1991 to March 1996. He is currently the president of Photonics Research, Fremont, California, and an associate professor of biomedical engineering at the University of Northern California, Petaluma. His research interests include optical signal processing and all aspects of optical engineering. He has more than 100 publications and presentations to his credit. He has been granted five U.S. patents. He is the coauthor of *Optical Signal Processing, Computing, and Neural Networks*, published by Wiley and Sons (1992). He is the editor of *Selected Papers on Optical Correlators* (1993) and *Selected Papers on Optical Neural Networks* (1994) published by SPIE. He is the coeditor of *Optical Storage and Retrieval: Memory, Neural Networks, and Fractals*, published by Marcel Dekker (1996). He is now coediting *Optical Pattern Recognition* for Cambridge University Press. He was a guest editor of a special issue on technologies for optical memory in *Optical Memory and Neural Networks* (1994), a special section on optical engineering in ophthalmology in *Optical Engineering* (1995), and two special issues on optical information processing in *Proceedings of the IEEE* (1996). He is on the editorial board of *Optical Memory and Neural Networks* and on the program committees of various international conferences, and is a reviewer of various scientific journals. He is a senior member of IEEE, and a member of SPIE, OSA, and the Japan Society of Applied Physics.

**Francis T. S. Yu** received his BSEE degree from Mapua Institute of Technology, Manila, Philippines, and his MS and PhD degrees in electrical engineering from the University of Michigan. During the period from 1958 to 1965, he was a teaching fellow, an instructor, and a lecturer in the electrical engineering department at the University of Michigan, and a research associate with the Communication Sciences Laboratory at the same university. From 1966 to 1980, he was on the faculty of the electrical and computer engineering department at Wayne State University. He was a visiting professor in the electrical and computer engineering department at the University of Michigan from 1978 to 1979. Since 1980, he has been a professor in the electrical and computer engineering department at The Pennsylvania State University. He has been a consultant to several industrial and government laboratories. He is an active researcher in the fields of optical signal processing, holography, optics and information theory, and optical computing. He has published more than 300 refereed papers in these areas. He is a recipient of the 1983 Faculty Scholar Medal for Outstanding Achievement in Physical Sciences and Engineering, a recipient of the 1984 Outstanding Researcher in the

College of Engineering, was named Evan Pugh Professor of Electrical Engineering in 1985 at Penn State, and was a recipient of the 1993 Premier Research Award from the Penn State Engineering Society. He is the author of six books entitled: *Introduction to Diffraction, Information Processing and Holography* (translated in Russian); *Optics and Information Theory*; *Optical Information Processing* (translated in Chinese); *White-Light Optical Signal Processing*; *Principles of Optical Engineering* (with I. C. Khoo); and *Optical Signal Processing, Computing, and Neural Networks* (with S. Jutamulia). Dr. Yu is a fellow of IEEE, OSA, SPIE, and PSC.

**Toshimitsu Asakura** received his MA in 1960 from Boston University and his DEng in 1965 from the University of Tokyo. He was a research assistant at the Physical Research Laboratories, Boston University, from 1957 to 1958 and a member of the research staff at the Research Laboratory of Itek Corporation from 1958 to 1961. After five years as a research associate at the Research Institute of Industrial Sciences, University of Tokyo, he became an associate professor in the Department of Applied Physics, Hokkaido University, Sapporo, Japan, in 1966. In 1971 he was promoted to professor at the Research Institute of Applied Electricity (now the Research Institute for Electronic Science), Hokkaido University, the position he now holds. Since April 1994, he has also been director of the above institute. His areas of research have been in optics and related fields, particularly in relation to the properties and applications of laser light. He has published more than 600 papers in technical journals and other publications. Professor Asakura is now vice president of both the International Commission for Optics and the Asian Pacific Optics Federation, president of the Optical Society of Japan, a fellow of OSA and SPIE, and a member of numerous technical societies in Japan. He received the Best Optics Paper Award from the Japan Society of Applied Physics in 1962, the Hokkaido Science and Technology Award in 1986, the awards from the Japan Society of Applied Physics in 1993 and 1995, the Shimazu Prize from the Shimazu Science and Technology Promotion Foundation in 1994, and the Order of Merit (Purple Medal) from the Japanese Government in 1996. He is a member of the advisory editorial boards of various international journals and the book *Progress in Optics*.