INTRODUCTION
The Defense Advanced Research Projects Agency (DARPA) has initiated a major new program in Artificial Neural Network Technology. This program addresses complex information processing and autonomous control problems, including problems that require real-time processing and response. If its promise can be realized, artificial neural network technology will provide powerful tools for a broad range of both military and commercial applications.

POTENTIAL ADVANTAGES
Artificial neural networks are systems for processing of information, the structure and function of which are motivated by analogies with biological nervous systems. In their analog for biological learning, they provide a rich and potentially powerful substitute for the algorithmic programming required by conventional information processing systems. The processing in artificial neural networks is based on relationships derived from data rather than abstract theory or expert knowledge. They are not programmed like conventional computers, but instead—like their biological counterparts—they are "trained." In a further analogy with their biological counterparts, they can continue to adapt and be retrained during use. These analogies lead researchers to hope that mature artificial neural networks will be:

- able to deal effectively and rapidly with a wide range of information processing and control tasks involving complex data sets, which may vary in space and time as the system deals with them;
- well-suited to the interpretation of limited or imperfect data;
- capable of providing appropriate responses to unforeseen stimuli;
- able to adapt to evolving conditions; and
- resistant to failure of individual components.

Because they are trained rather than programmed, development of artificial neural networks is expected to be much faster and less demanding than either development of conventionally programmed algorithmic systems or capture of expert human knowledge within the framework of expert system shells. Conventional algorithmic programming is a time-consuming and error-prone process that can only be carried out by skilled practitioners. Even after conventional programs are written and debugged, verification and life-cycle maintenance remain major undertakings. These factors have made software the major cost element of present complex information processing systems. Expert systems also require large amounts of skilled labor, on the part of both a human expert who already knows how to accomplish the target task and a “knowledge engineer” who seeks to capture the expert's knowledge in an effective system of rules. Neural networks' potential advantage in this respect is one of the most attractive aspects of the technology.

Artificial neural network technology provides an architecture for massively parallel computing that solves inherently, in a very natural way, the problems of distribution of processing tasks and information. Although the development of artificial neural network systems for specific applications is currently proceeding in software emulations, the ultimate benefit of the technology is expected to be realized when these systems are implemented in dedicated hardware that will provide enormous computing capability in compact packages.

THE DARPA PROGRAM
DARPA is currently at the halfway mark in a $33M, 28-month exploratory program to determine the utility of artificial neural networks for military applications. Accomplishments in this initial effort will shape the future direction of the program.

The objectives of this initial phase of the DARPA program are to:

- identify, investigate, and measure advantages of artificial neural networks over existing conventional technologies in addressing challenging problems;
• advance the state-of-the-art in artificial neural network theory and modeling; and
• develop and evaluate a range of hardware implementation technologies as bases for future construction of artificial neural network computers.

The components of this program are:
• application performance evaluation;
• model development and analysis; and
• hardware technology base development.

The table below summarizes the relationship of program goals to program elements:

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<th>Program Goal</th>
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<tr>
<td>Identify and investigate advantages of artificial neural networks relative to alternative (conventional) approaches</td>
<td>Application performance evaluation</td>
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<tr>
<td>Advance the state of the art in artificial neural network architectures, and learning methods</td>
<td>Model development and analysis</td>
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<td>Develop advanced hardware implementation technologies for future construction of large artificial neural network computers</td>
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**COMPARATIVE PERFORMANCE MEASUREMENTS**

This component of the DARPA program is evaluating the performance of software emulations of artificial neural networks (or of hybrid systems incorporating neural networks) for classification tasks that strain the capabilities of conventional approaches. The following applications were chosen as examples:

- automatic target recognition;
- continuous speech recognition and word spotting;
- sonar signal identification; and
- seismic signal discrimination.

For most of these applications, DARPA is providing standard data sets to be used for developing and training the classification systems and for evaluating their performance. System performance is being compared to that of the best available alternative technologies.

In addition to classification accuracy, performance criteria include:

- ease of development, both for the current exercise and for future expansions and adaptations;
- feasibility of implementation in dedicated hardware;
- processing speed in dedicated hardware as compared to conventional approaches; and
- fault tolerance—performance sensitivity to failure or degradation of one or more processing elements.

This research is still underway, but results to date are highly encouraging. Overall, artificial neural network methods have consistently equaled or exceeded the performance of the best available alternative approaches in each of the chosen applications, despite the fact that the neural network systems in each case are newly developed, while the performance of the best competing methods reflect many years of development effort. For example, in the sonar signal identification task, neural networks reduced the false alarm rate by a factor of 10 over Bayes-Gauss classifiers. The use of a hybrid neural network/Hidden Markov Model (HMM) in the word spotting task gave a factor of two reduction in word error rates compared to HMM methods without neural network processing. Similarly encouraging results are emerging for the other applications addressed in the current DARPA program.

While these early results from software emulations indicate the utility of artificial neural networks over a broad and heterogeneous range of applications, their anticipated performance when implemented in massively parallel hardware is a critical factor in evaluating the future potential of this technology.

**MODEL DEVELOPMENT AND ANALYSIS**

The model development and analysis component of the DARPA program is:

- fostering development of the next generation of artificial neural network model architectures;
- developing faster, more powerful, and more efficient training procedures;
- developing strategies for scaling up efficiently to large-sized networks; and
- determining the specific properties, limitations, and data requirements of new and existing artificial neural networks.

In the area of model architectures, topics of particular interest include use of nodal elements with enhanced processing capability; modular networks composed of multiple interconnected subnets; hybrid systems combining neural and conventional information processing; means for developing model architectures
and internal data representations that are particularly well adapted to specific tasks; and networks that modify their behavior in response to changing inputs or external conditions.

In the area of training, emphasis is on development of faster, more efficient training procedures that are robust to noise in the training data or to delayed feedback, and techniques that minimize the need for external intervention.

In the area of theory, topics of particular interest include determination of scaling properties of new and existing neural network models; the proper relationship of system complexity to the nature and quantity of available training data; analytic treatments of the performance capability, stability, convergence, and fault tolerance of new and existing networks; and analyses of formal relationships between neural networks and conventional techniques.

HARDWARE TECHNOLOGY BASE DEVELOPMENT

The hardware technology base development component of the DARPA program is examining a range of approaches for implementing neural network processing in dedicated hardware. These include purely digital designs, hybrid digital/analog designs based on CCD delay line techniques, purely analog designs, and longer-range optoelectronic approaches. Strategies using both on-chip and chip-in-the-loop learning are being developed for a variety of learning algorithms, including back-propagation, radial basis functions with RCE learning, simulated annealing, and more specialized methods for image processing and control.

The main emphasis to date has been on basic components. Some of these components are now complete and have delivered processing speeds appreciably higher than one billion interconnects per second. This is more than a factor of 10 higher than the fastest current supercomputers performing neural network emulations. Multi-chip brassboards based on some of these components are being planned and will be evaluated for application to realistic problems. Even with a modest scale of integration, these initial multi-chip assemblies are projected to offer speeds of more than 100 times faster than current supercomputer emulations.

The transition from chips to multi-chip networks will require optimization of I/O and control designs, packaging and temperature control, host interfaces, and many other considerations. The details of such designs will be different for digital versus analog designs, for on-chip versus chip-in-the-loop training, for different training algorithms, and particularly for the longer-term optoelectronic implementations with much higher numbers of interconnections and processing elements. Concepts for the use of these networks will undoubtedly evolve as more powerful processing hardware becomes available.