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A Decade of Neural Networks: Practical Applications and Prospects

Workshop Report

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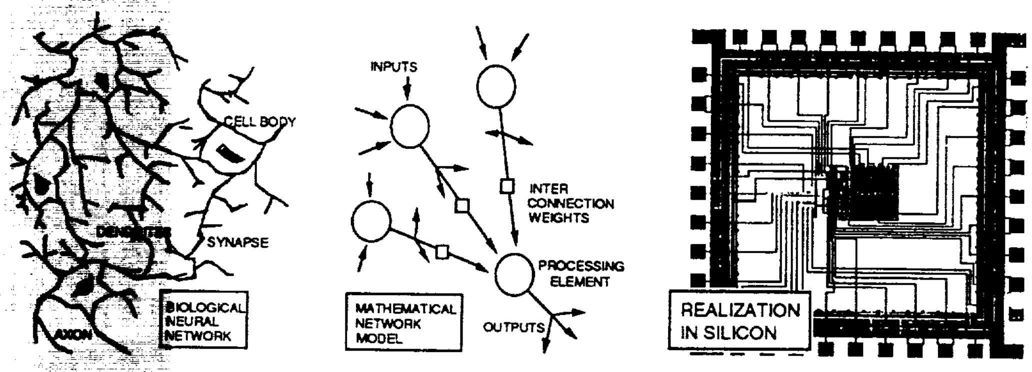
Editors



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Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Workshop Report:

A Decade of Neural Networks:
Practical Applications and Prospects

Sponsored by:

Ballistic Missile Defense Organization/Innovative Science and Technology Office

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Abstract

On May 11-13, 1994, JPL's Center for Space Microelectronics Technology (CSMT) hosted a neural network workshop entitled, "A Decade of Neural Networks: Practical Applications and Prospects," sponsored by DoD and NASA. The past ten years of renewed activity in neural network research has brought the technology to a crossroads regarding the overall scope of its future practical applicability. The purpose of the workshop was to bring together the sponsoring agencies, active researchers, and the user community to formulate a vision for the next decade of neural network research and development prospects, with emphasis on practical applications. Of the 93 participants, roughly 15% were from government agencies, 30% were from industry, 20% were from Universities, and 35% were from Federally Funded Research and Development Centers (FFRDCs).

The workshop began with a keynote address by Dr. Dwight Duston, Director of the Ballistic Missile Defense Organization/Innovative Science and Technology Office (BMDO/IST), who gave an overview of past, present, and future government and industry investment strategies for neural networks, with an emphasis on the need for a strong commercialization effort for this technology. A series of invited talks followed, which focused on a variety of applications both in control and signal processing. Topics such as fault diagnosis (vehicle engine health monitoring for automotives, space launch vehicle anomaly detection), pattern recognition (document analysis, automatic target recognition, artificial vision, face recognition), multiparameter optimization (unsteady aerodynamic control, resource allocation, path planning), image compression (video-conferencing, interactive education, home entertainment), and telecommunications (broadband access control, equalization, fraud detection, software reliability prediction) were covered in the presentations. A separate workshop proceedings, JPL Publication 94-10, includes abstracts and excerpts of presentation materials submitted by the invited speakers.

Following the talks, parallel working groups were formed. The working groups discussed the current state of the art; the competitive advantages of neural networks with respect to alternative methods; the high impact, high payoff directions to commercializing neural network applications; addressing issues such as technology insertion, technology acceptance, and enabling technologies; and finally prospects of industry-academia-government collaborative research and development. This report summarizes the discussions and recommendations of the working groups.

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Section I. Introduction

For over a decade, JPL has actively pursued neural network research on theory, architectures, algorithms, applications, and electronic as well as optical hardware implementations. The work at JPL has been sponsored primarily by NASA and several DoD agencies. As a Federally Funded Research and Development Center (FFRDC), JPL's role in this technology area has been complementary to U.S. industries and universities. JPL has focussed on technical issues, where JPL can offer certain "technology advances, unique facilities, and special expertise" that complement the ongoing work at universites and US industries. As part of the ongoing technology assessment for our sponsors, JPL hosted this workshop. The overall purpose of the workshop was to bring together the sponsoring agencies, active researchers, and the user community, to formulate a vision for the next decade of neural network research and development prospects, with emphasis on practical applications.

In order to focus the workshop on the practical aspects of neural networks, a series of invited talks emphasizing real world applications both in control and signal processing was presented. Topics such as fault diagnosis (vehicle engine health monitoring for automotives, space launch vehicle anomaly detection), pattern recognition (document analysis, automatic target recognition, artificial vision, face recognition), multiparameter optimization (unsteady aerodynamic control, resource allocation, path planning), image compression (video-conferencing, interactive education, home entertainment), and telecommunications (broadband access control, equalization, fraud detection, software reliability prediction) were covered in the presentations. A separate workshop proceedings, JPL Publication 94-10, includes abstracts and excerpts of presentation materials submitted by the invited speakers.

Following the invited presentations, three splinter groups were formed for parallel breakout sessions, to formulate recommendations for future neural network research and development. The remainder of this report summarizes their discussions and recommendations.

Section II. Working Group Summaries

In each of the three parallel splinter groups, emphasis was placed on applications of practical significance. Two of the three groups focused on the application areas of control and signal/image processing, respectively, whereas the third group addressed all application areas in general. The groups had representation from large as well as small industries, FFRDCs, government agencies, and academia. The group leaders represented small industry, large industry and government. Drs. Kenneth Marko and Lee Feldkamp of Ford Motor Company led the group on control applications. Demetrios Sapounas of the Naval Surface Warfare Center led the discussion on signal and image processing applications, and Dr. Azad Madni of Intelligent Systems Technology, Inc., led the third group on control, signal processing, and all other application areas in general.

During the four hour time period, the splinter groups addressed four topical questions in developing their recommendations. The questions were:

- What can neural networks do today that is unique or substantially better, compared to alternative techniques? What are the advantages of neural networks?
- What are some of the emerging high impact/high demand applications of neural networks and the technology(ies) needed to support them?
- What are the predominant barriers to neural network technology insertion/acceptance? How can they be overcome ?
- What roles should government, FFRDCs, industry and academia play in realizing the future of artificial neural networks?

There was significant overlap in the conclusions of the three groups. The following is a summary of the discussions, prepared primarily from the remarks of the splinter group leaders, highlighting relevant discussion points in each of the four topical areas.

1) Neural Networks Today

What can neural networks do today that is unique or substantially better, compared to alternative techniques? What are the advantages of neural networks?

Although the splinter groups were charged with the primary task of identifying some of the real "success stories" for Artificial Neural Networks (ANNs), almost every group directly or indirectly addressed the important question: "what neural networks cannot do and why?" Clearly, ANNs are playing an important role in the way people think about problems today. Many requests have surfaced to study problems using neural networks that were regarded as too difficult to tackle before ANN paradigms became widely known. However, it should be realized that ANNs represent only certain computational paradigms with their own specific strengths and weaknesses. ANNs by themselves are not a panacea for solving all problems. In fact, there are currently numerous efforts underway to combine and complement ANNs' capabilities with one or more other computational techniques such as fuzzy logic, AI/expert systems, and genetic algorithms. In defense of ANNs, however, there are many occasions when unrealistic expectations are placed on neural networks and complex (or sometimes even unsolvable) problems are improperly posed to them. Further, the ANN methodology is not yet developed to the degree that non-specialists can successfully apply the techniques to problems of any complexity they desire. As a result, there is sometimes a mismatch between the researcher or engineer capability and the complexity of the problem, leading to an abortive attempt to solve a problem, and subsequent dismissal of ANN technology.

From the examples presented by the discussion group members, however, it was clear that when properly applied, neural networks have indeed delivered results significantly better than other competing techniques in numerous cases. The following is a cross section of the cases brought out by the group members with first-hand experience, where ANNs have clearly left a mark.

After the emergence of neural networks, adaptive learning and trainable classifiers based on neural networks have become a rather routine part of many researchers' mathematical toolkits. Neural networks' unique capabilities in handling non-linear relationships and capturing ill-defined transformations from examples, where a complete model, data, or a priori knowledge is not available have led to a wide variety of applications. For instance, in the area of time series forecasting, ANNs are being put to the test on perhaps one of the most ill-defined temporal problems: predictions in financial markets. The London Office of the Union Bank of Switzerland (USB) is actively assessing the effectiveness of neural networks on predictions in the currency and mutual funds trading markets. Another growing application area for ANNs is pattern recognition for medical visualization aids and image processing. The commercial product, Papnet, developed by Neural Medical Systems, New York, performs PAP smear analysis (cancer screening) and is based on a neural implementation. Currently, the Martin Marietta Corporation in collaboration with Rose Health Care Systems is putting a mammogram analysis system in service for on-line screening of cancerous lesions. The system utilizes optical Fourier bandpassing and wavelet filtering to preprocess the image followed by a neural network for analysis and ill-defined pattern identification with final confirmation performed via optical correlation. Alacron Inc. is utilizing neural networks to perform classification on clinical neuro-physiological data, such as electro-encephalograms (EEGs) and Evoked Potentials (EPs), which show consistently accurate classification results even in the presence of noisy and corrupted recordings. This automated pattern identification and analysis system is being developed for real time acute care monitoring in the ICU and operating room setting.

In addition to these examples, there are several emerging ANN implementations and applications, such as optical character recognition (developed by AT&T for the US postal service), environmental controllers, image compression techniques, automotive engine health monitoring, and system modeling. Although in many such cases, the technical advantages of neural network methodology are clear, neural networks have not yet been accepted as routine procedures.

If neural networks clearly offer computational benefits that could be translated into cost reduction, speed enhancement, and/or system (hardware/software) simplicity, then what has stopped them from being widely accepted and inserted in large numbers of applications? A majority of the participants acknowledged that the field of neural networks has not only had a long history, but it has also received significant research dollars, federal as well as commercial, particularly in recent years. Therefore, for the field of neural networks to remain alive and vibrant, it must enter into real-world applications in a substantial way in the near future. There are clearly numerous application possibilities that could, in principle, become economically viable at this time. However, unless the early applications result in a broad market penetration through a notably high demand or high impact, the field of neural networks may once again drift and possibly dissolve into some other all-pervading computational paradigm. This discussion, therefore, led the groups in a natural way to the next posed question:

2) Future Applications and Relevant Technologies

What are some of the emerging high impact/high demand applications of neural networks and the technology(ies) needed to support them?

This part of the discussion generated a truly overwhelming list of applications. The applications could be divided into two broad classes. The first set of applications have emerged from several narrowly defined but quite complicated requirements of DoD, NASA and other agencies, which are driving certain application-specific neural network development efforts (e.g. various forms of real-time automatic target recognition, guidance and control of an interceptor, autonomy in planetary rovers, etc.). Although results of such efforts would be complex high performance neural network systems, immediate demand for such systems would perhaps be low, until the subsequent development of commercial counterparts of these sophisticated systems. The second set of applications, primarily characterized by their potential high demand, would arise from the commercial markets. Four broad application areas of neural networks that were viewed as potentially high impact or high demand candidates by a majority of the participants are described below.

A) Future Applications:

Transportation

One of the identified areas where neural networks are expected to have high demand and a significant (performance) impact in the near future is transportation. The applications would range from vehicle health management for (automotive) engines leading to lower emission and higher efficiency transportation to intelligent vehicles and better traffic management. In the case of power train diagnostics and control, for example, VLSI implemented compact neural network circuits could become an integral part of "under-the-hood" engine computers. It was recognized that this area truly represents a high demand (the sheer number of vehicles) and could be substantially impacted by low cost, easily deployable, neural network circuits. Furthermore, neural net classification techniques may also be incorporated into drunk, fatigue, and/or high G monitors. Automated route planning, both centralized and distributed in vehicles, has a potential to become an integral part of the Intelligent Vehicle Highway System (IVHS) and could greatly benefit from neurally inspired algorithms [1].

Health Care

The vast medical field has a lot to gain from the applications of neural networks to a variety of ill-defined pattern recognition, classification, multiparameter data interpretation tasks, and control problems. Most of these tasks are currently performed by humans, usually visually, with a significant subjectivity and uncertainty in the outcome. In the near future, neural network-inspired techniques are expected to appear in a variety of ill-defined classification, trend analysis, and overall medical data/image interpretation tasks to assist a medical practitioner with better analytical tools (i.e., medical aids). Clearly, due to the legal ramifications of implementing any new techniques in the medical world (and the difficulty of getting Federal Drug Administration (FDA) approval for new equipment, etc.), commercial development of such applications must follow a slow and arduous path. Perhaps the future revamping of the medical system with an emphasis on cost savings may allow better reception for introduction of such new technologies. Applications such as monitor automation (e.g., EKG or multi-sensor on-line) and medical life support control will have to await changes in the medical/legal system. Physiological signal-driven artificial limbs or prostheses may also incorporate neural algorithms, hardware, or simply physiological understanding derived from neural net research.

Industrial robotics, manufacturing, and process control:

Industrial robotics could be heavily impacted by neural networks in the time frame of the next ten years. The specific areas range from automated quality inspection on assembly lines to fault-tolerant, adaptive sequencing/scheduling and resource allocation operations. In addition, on-line process control in chemical plants, based on multi-sensor multi-modal input parameters, is an ideal problem for neural network solutions.

Human-machine interface:

The next high demand application area for neural networks identified by the workshop is in the rapidly evolving human-machine interface field. In particular, hand-written character recognition, large vocabulary speech recognition, and speech synthesis are the applications attracting considerable attention today. Also, several participants believed that combinations of fuzzy logic and neural networks are going to find wide-spread applications in the day-to-day situations of home security, home health monitoring/energy management, and home appliance monitoring/maintenance (i.e., "smart house").

B) Relevant Technologies:

Although the field of neural networks is not new and a variety of useful, real-world applications with clear benefits is already in sight, our understanding of the variety of algorithms used by real biological neural networks and their architectural details has only scratched the surface. Clearly, more research is required to develop a better understanding of the richness and fidelity of biological nervous systems in order to exploit the full potential of ANN. Better theoretical underpinnings are needed, especially in the areas of biological modeling and learning techniques (e.g., bifurcating or spiking networks). Further, the scalability of many of today's popular ANN algorithms for supervised and unsupervised learning needs to be explored and established. Other areas that should receive researchers' attention include better data representation in large networks and inexpensive scalable and accessible hardware. Improved analog-to-digital interfaces and tight coupling of sensors and processors were also cited as important supporting technologies for future high impact/high demand applications.

The overall goal of artificial neural networks is to learn from nature's successes and to mimic them in order to accomplish intelligent tasks not easily performed by conventional (sequential) computing techniques. The continuing evolution of life on the planet has experimented with a large variety of sensing devices and information processing architectures in biological organisms, covering an enormous spectrum of capabilities and varying degrees of intelligence. An important architectural aspect of the biological "processors" is their full and direct integration with biological sensors utilizing highly parallel, direct, and therefore quite efficient interfaces. The variety of biological computing architectures, sensors, and the communication links between them is truly amazing. To dramatically enhance the overall effectiveness of ANNs, therefore, sensor-processor integration must receive serious attention. An example of such tight coupling between sensors and processors, discussed at the workshop and described below, involves the integration of low-power analog VLSI ANN chips in a 3-dimensional cube architecture, which receive parallel input directly from the back of a focal plane sensor array.

Sensor-processor integration for smart vision:

A technology opportunity that lends itself to artificial-vision-related applications utilizing tight coupling between sensors and processors is the 3-D Artificial Neural Network (3DANN). The 3DANN consists of a stack of thinned VLSI neural network VLSI chips directly mated to an imager array [2]. Offering high density and massively parallel "focal plane" processing, this smart IC "sugarcube" could be used in a variety of applications, such as a smart "eyeball" for industrial robotics, autonomous space exploration, and automatic target recognition for BMDO's interceptor application. The cube offers tremendous speed potential. (For example, nominally a cube with a 128 x 128 pixel array as a front end will achieve over 10^{13} interconnects/sec processing speed, whereas a cube with 1024 x 1024 pixel array will surpass 10^{18} interconnects/sec). However, there are major challenges in learning to train, control, and develop algorithms for, and communicate with, such a network that need to be addressed in future research to be able to put the unprecedented computing power of such a cube to use in complex applications, going beyond current image processing functions.

3) Overcoming Barriers to Technology Insertion/Acceptance

This topic generated the most compelling discussions in terms of what needs to be done differently in the future to facilitate the insertion of neural network ideas and technology into the mainstream. In addition to the legal ramifications discussed above, which must be addressed through proper channels, and the general limitation on research funds in the current fiscally lean times, three major areas surfaced as barriers to technology acceptance:

1) Perception problems
2) Lack of technical understanding on the part of the prospective user community
3) Lack of coordination

These barriers as well as recommended solutions for them are presented below.

Perception

Neural networks have suffered from a number of perception problems which can be attributed to a variety of causes, most notably poor marketing on the part of researchers. The name "neural" itself without proper understanding of the subject has been a major issue, with reactions ranging from fear due to certain religious beliefs to the perception of science fiction. Due to the excessive hype ANNs encountered several years ago, there have been inflated performance expectations, eventually leading to disappointment with the technology and its cost effectiveness.

Most of these perception-related problems could be addressed with a good marketing strategy and improved advertising. Compelling demonstrations and user involvement early in the development cycle will also dispel some of these false impressions. Education and training discussed in more detail below will also improve the appeal of neural networks. Finally, incremental acceptance as ANN products slowly filter into systems will gradually change these perceptions.

Education

The lack of technical understanding may be the biggest barrier to technology insertion, but it is also the easiest to address with the proper allocation of funds. Explicit knowledge about neural systems is still limited, resulting in a "black box" syndrome (a lack of understanding of the decision-making properties of an artificial neural network) and wariness to employ such networks. With only a few rigorous courses in neural networks in the engineering curricula, there is a reluctance on the part of engineers to utilize neural networks. Specifically, this reluctance is reinforced by their other training which emphasizes a model-based approach to problem solving, contrary to the model-free ANN. These problems can be clearly addressed by appropriate education at all levels. By creating an interdisciplinary core curriculum which exposes students to neural network ideas, both engineers and non-engineers (e.g. future business managers) will be more receptive to novel approaches for problem solving. In addition, a theory akin to classical circuit theory and associated textbooks need to be developed for use in the engineering curricula.

Several of the workshop participants argued that it is important to develop guidelines and criteria for "ANN architecture optimization" and "training-set selection" for a given class of problems for prospective users of ANNs. Finally, there is a lack of system development knowledge and domain understanding, as well as confusion between "adaptation" and learning, that needs to be addressed. Teaming with system engineers and domain experts as well as sponsoring tutorial presentations and educating management will smooth the way to technology acceptance.

Coordination

There are several other important barriers to technology insertion that can be loosely associated with problems of coordination. One is a competition with artificial intelligence (AI) and classical techniques, which can be easily overcome by fostering complementarity with these techniques. Neural networks with their unique set of strengths and weaknesses need to be utilized in conjunction with other methods and there is no need for competition, especially with insufficient knowledge of either of the technologies. However, it is important to provide relevant benchmarking between differing techniques so that the technology can be accepted and understood within the existing knowledge framework. For example, the wrong attributes are often compared, such as the apparent inaccessibility of the internal representation of the problem/situation generated by an ANN with an easily accessible (often incomplete, distorted, or totally inappropriate) plant model while using other rule-based techniques. This can easily lead to misunderstanding and missed opportunities. Finally, a direct connection between research investment and revenue generation needs to be established to further encourage applied funding opportunities. The workshop recommended both introducing ANN technology into existing products in an incremental add-on style (e.g., on-line engine health management in automotive industry) as well as bringing totally new capabilities into innovative high demand markets (medical image and data interpretation).

4) Roles of Government, FFRDCs, Industry and Universities

What roles should government, FFRDCs, industry and universities play in realizing the future of artificial neural networks?

The participants acknowledged the increasing and fruitful interactions among the FFRDCs, industry, and academia over the last few years, encouraged by new and old mechanisms for formal relationships, such as the Small Business Innovative Research (SBIR), Small Business Technology Transfer (STTR), Technology Reinvestment Project (TRP), and Advanced Technology Program (ATP) grants and agreements. However, the groups felt that there is always room for improvement in coordination, primarily to avoid expensive duplication of efforts. In addition to the general roles for each of the parties, the groups also came up with some specific suggestions. For example, it was expressed that the government's attempt to catalyze commercial applications of emerging technologies through new programs such as TRP and ATP is excellent. It strongly encourages industry to make serious investments in high payoff technologies. However, the government needs to continue funding high risk research and development areas in ANNs that will not be undertaken by industry. Overall, the government's role would be in:

- Infrastructure development
  - Guide consortia creation and operation
- Intelligent funding
  - Select high payoff/high risk efforts that would not be undertaken by industry
  - Fund needed support technologies (hardware, theoretical work)
  - Fund both university research and curriculum development

FFRDCs in their unique non-profit role should support government in technology assessment, policy making, and program development. Their role in research and development should be restricted to only such activities that are not being undertaken by industry or academia. Furthermore, they must spend significantly more effort in transfer of their technology to industry in a timely fashion.

Industry, on the other hand, must lead ANN technology commercialization and proliferation, as they would be the immediate and first beneficiaries. Large industries should actively work on opportunities for collaboration with small businesses and universities. Their role could also include:

- Creation of forums for information exchange (to expose small businesses and universities to industry problems, and to learn about innovative technologies being developed by them)
- Encourage university professors to take sabbaticals in industry (visiting scientists)
- Support summer hiring programs and industrial internships for university students

Finally, academia will continue to take a major responsibility for the required basic research and theoretical studies, but should also work on industry-relevant problems. In that light, several participants pointed out some of the useful steps already taken by several universities:

- Encourage professors to take sabbaticals in industry
- Support internship programs to encourage students to work in industry
- Develop flexible working relationships with industry
- Educate industry and government on emerging research themes, accomplishments, and findings
- Set up core curriculum for engineering science and arts that includes neural networks

Section III. Panel Summary

The workshop ended with an assessment panel composed of sponsors from a variety of government agencies as well as leaders in both small and large industry. Each of the nine panelists gave their perspective of the neural network field. Although some agencies described budget constraints, a cautious optimism came through. Neural networks are a viable new emerging technology. After going through a period of hype followed by hibernation, the current atmosphere is lean and mean, which may just provide the required focus of energy to transfer neural networks from the world of theory to that of practice.

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Appendix
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16. Abstract

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