Applications of Neural Networks in Telecommunications

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ABSTRACT: Many researchers today prefer to use the term *computational intelligence*, to describe techniques such as neural networks, fuzzy logic and genetic algorithms. These are now seen as complementary rather than competing methods. A number of current applications of neural networks to telecommunications are summarised below and some hot topics for future research in this area are given. There is still much work to do in increasing the application of *intelligent* techniques by industry so that these techniques feature in developed systems. Some proposals for increasing the application of intelligent techniques to commercial communications systems are cited, based on academic-industrial collaboration within Europe and supported by EC Networks of Excellence, which aim to bring this technology transfer about.

KEYWORDS: neural networks, telecommunications, training, pattern recognition, control

CLASSIFICATION OF INTELLIGENT SYSTEMS

Intelligence is defined as the capacity for understanding or the ability to perceive and comprehend meaning. As such, numerous researchers are attempting to develop intelligent systems and intelligent methods to solve complex problems. The word *intelligence* can mean news or information. An alternative use of the term *intelligent* describes a system or method able to modify its action in the light of ongoing events. Such systems are *adaptive* and give the appearance of being *intelligent* as they change their behaviour without the intervention of a user.

These two legitimate uses of the term *intelligent* are important as they describe systems in common use. The first usage includes all rule-based methods such as artificial intelligence, fuzzy logic and genetic algorithms. The second usage comprises techniques such as neural networks which aim to perceive and comprehend the significance of the data with which they are trained. Neural networks are best distinguished from other intelligent techniques in that they are non rule-based and can additionally be made stochastic so that the same action does not necessarily take place each time for the same input. A stochastic behaviour allows a neural network to explore its environment more fully and potentially to arrive at a better solution than linear methods might allow.

The partition of systems into rule-based and non-rule-based categories is necessary in order to understand how these systems work and where they may be applied. It is often easier to gain acceptance for the first type rather than the second. The reasons are fairly clear; it is normally possible to gain an understanding of how the rule-based intelligent system arrives at its solution and this can be used to verify that this system will operate within certain parameters. With an artifical neural network (ANN) system, it is harder to extract meaning from the values of the neuron weights and the connections between neurons especially as, under training, these systems often find different solutions in successive runs.

Since the data presented to the intelligent system will normally be pre-processed and sometimes post-processed, intelligent systems are often hybrid in nature. In many cases, the intelligent part of the system is evident only during parameter selection, for example. In a similar way, a hybrid system might comprise a fuzzy logic controller, whose membership functions are selected by an ANN. Describing such systems as intelligent allows the designer to avoid being explicit about the techniques used and the proportion of their usage.

USING INTELLIGENT SYSTEMS

Intelligent systems require training or expert knowledge. Before AI and ANN techniques are developed, a large amount of training data is required either to build the database or to train the network respectively. This training data is often hard to obtain and may not be a good representation of the total data set. Using AI, success is often achieved in the early stages of building the rules and this encourages the user to further develop the system.

With ANNs in particular, some experience in the art of constructing and training a network is required before any success is likely. Where ANNs are sold as a *black box* through which data is passed, new users are often disappointed by the results and ANNs are rejected as a result. Experience in the modes of failure during the training of ANNs is necessary in order to redesign the network.

Since this implies a certain level of expertise and in many cases means that each ANN solution is unique, industry is not prepared to spend the time in acquiring this expertise for just one task, which may be only a small part of the overall project. Data is normally pre-processed or parameterised before being presented to an ANN. There is an art in choosing the best method, since if an inappropriate method is chosen, the network's weights might not converge at all during training. This is the antithesis of industry's needs. If ANNs cannot be delivered as a turn-key package, then the effort required to implement them may be too great.

Finally, in an intelligent system, where *a priori* information exists, it should be used either in a preprocessing stage or to address the problem using conventional methods. There is no value in forcing the intelligent system to learn what is already known.

APPLICATION AREAS OF ARTIFICIAL NEURAL NETWORKS

The following features have been advanced for artificial neural networks by Dorffner (1999) as part of a joint Networks of Excellence activity in the development of a technological roadmap:

Strengths	**Application areas**
Ability to solve data-intensive problems	Where a conventional process is not suitable or cannot easily be defined or cannot fully capture the complexity in the data,
Rapid prototyping	
Adaptation and learning	where stochastic behaviour is important,
Scalability	where an explanation of the network's decision is not required.
Nonlinearity	

Table 1: Features of artificial neural networks

Typical problems addressed by neural networks include pattern recognition, signal processing, time series processing, unsupervised clustering, visualization of complex data, data compression, control problems and image processing.

Within each of the above areas, there is a wide range of current applications. For example in the pattern recognition field, sub-topics include image processing and security applications, fingerprint recognition, signature verification, secure entry systems and intelligent alarms. It can be seen that these do not operate on the the communications channel or control a network, but are added-value services to provide superior user interfaces or additional security. Some other examples of existing neural network pattern-recognition applications in telecommunications are shown in Table 2.

Data interpretation	Table Structure Interpretation & Text Recognition for Conversion of Telephone Company Tabular Drawings
	Arabic Character Recognition System
	Real-Time Identification of Language from Raw Speech Waveforms
	Temporal Difference Learning Applied to Continuous Speech Recognition
	Keyword Search in Handwritten Documents
	Face Recognition
	Self-organizing Finite State Vector Quantization for Image Coding

Table 2: High-level applications

Some specific current and past telecommunications applications for artificial neural networks are listed in Table 3 below.

Equalisers	Programmable VLSI Neural Network Processors for Equalization of Digital Communication Channels

	Adaptive Equalization
	Channel Equalization by Distribution Learning
	Equalisation of Rapidly Time-Varying Channels Using an Efficient RBF Neural Network
	Equalization and Fast Adaptive Signal Recovery in Very Heavy Tailed Noise
	Neural Receiver Structures Based on Self-Organizing Maps in Nonlinear Multipath Channels
Network Design, Management, Routing and Control	Adaptive Routing in Very Large Communication Networks
	A Distributed Reinforcement Leaning Scheme for Network Routing
	A Learning Model for Adaptive Network Routing
	Optimal Traffic Routing Using the Self-organization Principle
	Hopfield Optimization Techniques Applied to Routing in Computer Networks
	Scheduling Problems in Radio Networks Using Hopfield Networks
	New Q-Routing Approaches to Adaptive Traffic Control
	Dynamic Routing in ATM Networks with Effective Bandwidth Estimation
	Intelligent Capacity Evaluation/Planning with Clustering Algorithms
	Neural Networks for Network Topological Design
	Location Prediction in Mobile Networks
ATM network control	ATM Call Control by Neural Networks
	A Hybrid Admission Control Scheme for Broadband ATM Traffic
	ATM Multimedia Traffic Prediction
	Constrained Optimization for Switching
	ATM Cell Scheduling for Broadband Switching Systems
	Traffic Trends Analysis
	Control of Self-Similar ATM Call Traffic by Reinforcement Learning
	Hardware Implementation of Reinforcement Learning for Call Admission Control in Networks for Integrated Services
	Generation of ATM Video Traffic
	ATM Traffic Policing using a Classifier System
	Computing Blocking Probabilities in ATM Virtual Subnetworks
Fault management	Identifying Fault-prone Software Modules
	Learning Index Rules and Adaptation Functions for a Communications Network Fault Resolution System
	Using Distributed Neural Networks to Identify Faults in Switching Systems
	Pre-processor for a Fault Diagnosis Expert System
Network Monitoring	Prediction of Access Line Growth
	Techniques for Telecommunications Fraud Management
	Learning Customer Profiles to Generate Cash over the Internet

Table 3: Selected artificial neural network applications in communications

HOT TOPICS IN COMMUNICATIONS

The IEEE Communications Society is active in developing a list of state-of-the-art topics in communications. Some of these are areas in which neural networks have a rôle, such as signal processing for beamforming, adaptive antennas, consumer communications, radio resource management and mobility management. This list will be developed and displayed on the Communications Society web page in the future (Kartalopoulos, 1999).

Beamforming employs signal processing in transmitting information over multiple antennas. It is also used for receivers to create steerable arrays. The purpose of beamforming is to minimize interference whether this be caused by fading, reflections or the effects of multi-user interference. If the channel is unknown or is changing, an adaptive antenna system will prove to be an advantage. Adaptive antennas can also offer capacity enhancements or allow higher bit-rates to be used.

Consumer products will soon have the capability of high-speed communications. This requires low cost and low power electronics. However, the domestic environment may not be RF-friendly so that an intelligent and adaptive receiver can improve the throughput without requiring an increase in transmitter power. One such wireless communications standard is Bluetooth; Bluetooth has to compete with IrDA (Infrared Data Association) which is a line-of-sight system, whereas Bluetooth is not.

Wireless systems are demanding higher spectrum efficiency as applications become more bandwidth-hungry. Radio resource management is essential and requires dynamic channel assignment, interference avoidance, propagation prediction and automated planning techniques which are conventional neural network applications. Handoff requires a decision which is similar to a fuzzy logic rule.

When a user moves between a fixed and mobile platform, it will be essential that this user can enjoy the same services and applications transparently. Research continues into intelligent systems to implement dynamic routing, wireless ATM and location prediction.

EUROPEAN INITIATIVES

The European Commission agreed to fund NEuroNet (the European Network of Excellence in Neural Networks) and other Networks of Excellence (NoEs) in 1994. It recently agreed to continue the funding of these networks until 2001. For the next two years, NoEs are required to concentrate on three areas:

1. industrial clubs
2. development of a technological roadmap
3. joint activities with other NoEs.

Technology transfer from research laboratories to industrial applications is essential in order to justify on-going research. One successful method of implementing this transfer has been the setting up of industrial clubs comprising industry and academia. Each collaborating industrial partner pays a small membership fee and there is often some matching government support as well. By holding seminars and producing feasability studies the applications of the technology can be demonstrated. Industrial partners can also share their experiences of the technology with case studies. By this means, industry does not need to maintain in-house expertise in intelligent techniques, but can keep abreast of developments in the area and can call in experts as and when they are required.

The technological roadmap is intended to include:

- a business outlook analysing market trends and current and visible future applications of the technology
- a technological view that identifies the current status of the technology at its progress given the R&D activities worldwide and their potential for success.
- a description of research needed in Europe to confront market and technological challenges and to ponpoint possible gaps or disconnects.
- an analysis of the contribution of the nodes to the progress of the technology and its takeup.
- a definition of milestones at which the integrity and validity ofthe forecast would be checked.

The NoEs which embrace computational intelligence (CI) include NEuroNet (neural networks), ERUDIT (fuzzy technology and uncertainty modelling) and EVONET (evolutionary computing). Other NoEs work in related areas such as language and speech, where synthesis and recognition applications make use of CI, and computational logic where applications in Prolog, for example, are developed.

REFERENCES

Dorffner (1999), Internal Report for NEuroNet, http://www.kcl.ac.uk/neuronet

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