# Neural Network Architectures with Time Delay Connections for Nonlinear Signal Processing

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Nonlinear signal processing using neural network models is a topic of recent interest. Recurrent networks offer a potentially rich and powerful modelling capability though are often difficult to train. On the other hand, simpler network structures which have an overall feedforward structure, but draw more strongly on linear signal processing approaches have been proposed. The resulting structures can be viewed as a nonlinear generalizations of linear filters. This workshop addressed some issues surrounding networks which may be viewed in a nonlinear signal processing framework, focussing in particular on those which employ some form of time delay connections with possibly limited recurrent connections.

The workshop was opened by **Andrew Back** (University of Queensland) who gave an introduction to nonlinear signal processing techniques, focussing on recent neural network approaches. A number of theoretical issues were raised by participants. **Bill Horne** and **Lee Giles** (NEC Research Institute, "Issues in Representation: Recurrent Networks as Sequential Machines" ) presented results showing the topological relationship between neural networks with restricted time-delay feedback connections and specific subclasses of Finite State Machines (FSMs) known as finite memory machines and definite memory machines. Preliminary results addressed the issue of representational bias and how this bias influences a procedural bias in the architectures. **Paolo Frasconi** (University of Florence, "Computational Capabilities of Local-Feedback Recurrent Networks") considered issues relating to processing sequences of symbols. In particular, the question of whether a "large enough" network with local feedback connections can emulate the a fully-recurrent network working in short-term regime was considered. **Jose C. Principe** (University of Florida, "Properties of Recursive Memory Structures") discussed the recently developed gamma memory model for temporal processing. In this model, the usual time delay shift operator is replaced by a more general adaptive operator. Some important applications were

discussed, including SAR imagery with significant possible improvements indicated. **Tina Burrows** and **Mahesan Niranjan** (Cambridge University Engineering Department, "The Performance of Recurrent Networks for Classifying Time-Varying Patterns"), discussed the effect of the recurrent connection in forming a dynamic decision boundary dividing the input space into both context-sensitive and context-insensitive regions.

A number of new architectures were presented. **Roderick Murray-Smith** (MIT, "A Local Model Net Approach to Modeling Nonlinear Dynamic Systems") presented results showing how *a priori* knowledge may be introduced into general modelling structures termed Local Model Networks. These networks can be seen as RBF nets with a general model of the inputs replacing the simple weights. The approach has proven to be practical in a number of applications such as rolling mills, physiological modelling, robot actuator modelling and AC drive control. **Lokendra Shastri** (ICSI, "A Spatio-Temporal Approach to Visual Pattern Recognition"), described an approach to visual recognition where an image is converted into a spatio-temporal signal via scanning, and processed by a multi-layer network containing variable delay links and self-recurrent connections. This approach offers several advantages including: shift invariance in the direction of scan, explication of local image geometry, the ability to process inputs of arbitrary length, and a significant reduction in the number of network parameters. **Tony Bell** (The Salk Institute, "Nonlinear Infomax With Adaptive Time Delays") presented a neural net which uses a new learning algorithm to minimize mutual information between outputs and maximize their individual entropies. The network performs Independent Component Analysis (ICA) and is suitable for blind separation and blind deconvolution of speech signals. **Jerome Soller** and **Frank Stenger**, (University of Utah, "The Sinc Tensor Product Network and Nonlinear Signal Processing") presented results on a neural network architecture known as the sinc tensor product (STP) network. The STP network is capable of providing accurate approximations to solutions of engineering problems. STP network optimization has similar time complexity to radial basis function network optimization and lower time complexity than backpropagation for the multilayer perceptron.

Some specific real world applications were also presented. **Chuck Anderson** (Colorado State University, "Discriminating Between Mental Tasks Using a Variety of EEG Representations"), presented results concerning the use of neural network models in EEG pattern recognition for application in prosthetic communication devices for the disabled. The difficulty of this problem is in finding suitable EEG representations which allow classification to be performed. Some promising experimental results were reported. **Thomas Enders** (Technical University of Munich, "Beer brewing: A progress report on modeling batch fermentation processes") presented results on the use of neural networks as one component within an overall system for control and optimization of batch fermentation processes. Temporal neural networks were used to adaptively model the nonlinear dynamic properties of the process using a one-step ahead prediction error criteria.

Our thanks to the participants and speakers, in particular, Bill Horne & Lee Giles (*horne@research.nj.nec.com*), (*giles@research.nj.nec.com*), Paolo Frasconi (*frasconi@anduril.cselt.stet.it*), Jose Principe (*principe@synapse.ee.ufl.edu*), Roderick Murray-Smith (*rod@psyche.mit.edu*), Lokendra Shastri (*shastri@icsi.berkeley.edu*), Tina Burrows & Mahesan Niranjan (*tb119@eng.cam.ac.uk*), (*niranjan@eng.cam.ac.uk*), Tony Bell (*tony@salk.edu*), Jerome Soller (*soller@asylum.cs.utah.edu*), Chuck Anderson (*anderson@cs.colostate.edu*), and Thomas Enders (*ta131ab@sunmail.lrz-muenchen.de*). Workshop notes will be available for retrieval via ftp (contact the organizers for access details).