# Final Report on EPSRC Research Grant GR/L19232 Analysis of On-Line Learning in Neural Networks

## Summary

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The aim of the project was to exploit a general framework for analysing online learning in multilayer neural networks, developed by the principal investigator and collaborators, to examine a variety of training scenarios and methods which are of interest to researchers carrying out real-world on-line training of neural networks. The main objectives of the project were: 1) To examine analytically the effects of various types of noise in on-line training. 2) To study the efficiency of Gaussian regularizers for improving network performance in various noisy training scenarios. 3) To examine analytically existing heuristic techniques, currently used in neural networks training, and to suggest novel methods for improving the training process. The main achievements of the grant are summarised below.

**Learning from noisy training examples:** Gaining insight into the effects of different noise types, corrupting the training data, on the dynamics; this was examined for both Gaussian output and model (weight) noise. Deriving analytically exact asymptotic solutions, optimal learning rate decay schedules and optimal prefactors for two layer on-line training scenarios under the conditions of noise or structural unrealisability. Deriving globally optimal single and multiple learning rates in various scenarios and globally optimal learning rules in several simple cases.

**Regularization:** Learning the effect of Gaussian regularizers in general and optimal regularizers in particular for noisy and over-realizable scenarios (training with redundant parameters).

**Learning rules:** Devising and analysing different learning rules aimed at speeding up training and at improving learning performance, mainly by breaking emerging symmetries in the transient. Analysing natural gradient descent (NGD) and its variations throughout the learning process under optimal and sub-optimal training conditions. Exploring analytically the advantages and limitations of matrix-momentum methods for both NGD and Newton-rule based gradient descent in multilayer networks.

**Related areas:** Analysing the role of biases in two-layer neural networks within the framework of on-line learning. Studying the different learning dynamics of the biases and the weights, studying analytically on-line learning of drifting rules in multilayer networks, where the task itself is not stationary. Examining the Bayesian approach to on-line learning in single and multilayer networks within the statistical mechanics framework using the Extended Kalman Filter approximation. Calculating the capacity of networks generated by various constructive algorithms. Examining simple error-correcting codes and the relation between statistical mechanics approximation methods and belief propagation.

The project resulted in 28 publications and 17 conference presentations. Some of the key publications are available through this web-page.

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