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A Generalization Ability of Multi Layer Neural Networks with Fault-Tolerance

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1 Introduction

Neural networks(NN), which is an engineering model of biological neuron network, have variety of characteristics including learning, parallel distributed processing, generalization, and fault-tolerance.

The generalization ability of the multi layer NNs is the ability to find out rules or regularity from the given learning pattern set. This means that excessive parameters in the networks affect the generalization ability because of the over fitting to the learning pattern.

On the other hand, fault-tolerance inherently requires redundant components which may involve excessive parameters. Thus, it can be considered that these two characteristics are in the position of trade-off.

But some recent works showed that networks with good fault-tolerance also have good generalization ability.

This research examines these two abilities of NNs and investigate the relationship between these abilities. To explore the mechanism of the relationship, some network characteristics are proposed and examined.

2 Multi Layer Neural Networks

Multi-layer NNs consists of units and links which connects units. The nodes are grouped into layers and nodes are perfectly interconnected with nodes in the successive layer. Each links has a weight value, and the output value of the unit is multiplied by the weight value, then sent to the units in the next layer.

Learning is a process that determines the weight value from a given pattern set. In this thesis, Back-Propagation(BP) and Fault-Tolerant Back-Propagation(FTBP) learning algorithms are used. Both of these are based on the gradient descent optimization, which reduces the value of the cost function. The cost function of FTBP includes the evaluation of fault-tolerance as well as the ordinary BP cost function , i.e. , a measure of the error against the learning set.

As the benchmark problems, band-shaped distributions (BSD) are introduced. BSD is a 2-input 1-output pattern based on the normal distribution around y=0.5 line, and has two versions, discrete (BSD-d) and continuous (BSD-c). In BSD-c, input values are uniformly sampled in the rectangle area and the output takes the value of the normal distribution function of the input value. BSD-d takes two random inputs and its output is determined to 0 or 1 by the probability given by the normal distribution function of y-axis value of the input.

3 Characteristics of the networks

Generalization ability is usually measured by evaluating the performance, or error, against the training pattern set. In this thesis cross validation scheme, as well as the ordinary test-pattern and training-pattern method, is employed to measure this ability more accurately.

The most important factor which affect the generalization ability is the over-learning and non-uniqueness of the network representation.

To illustrate these factors, some characteristics of networks are examined: internal representations, statistics of hidden unit outputs, separate line of hidden units, derivative of hidden units, smoothness of the whole network function, statistics of weight value, and output distribution. Among these values, derivative of hidden units and smoothness of the network function can be considered to greatly affect the generalization ability and fault-tolerance.

4 A new definition and measure of fault-tolerance

In the research field of Fault-Tolerant Computing, fault-tolerant is defined as a characteristics of a system which meets the specification (ensures the proper operation) under the existence of some class of faults. An application of this concept to the NN yields a concept of essential links and brought FTBP model. But this measure is not always adequate for NNs because of the inherent difference between digital computer systems and NNs.

In this thesis we introduce a new fault-tolerant measure and definition, which focuses on the difference between the ordinal function and function under faults, rather than specification of the network.

Simulation results show that this new concepts gives a good measured value which matches to the ordinary sound of the word "fault-tolerance", and opens a prospects to the evaluation of multiple faults.

5 Fault-tolerance and generalization ability

Simulation results with BSD-d pattern sets show that good generalization is obtained by the networks which has good fault-tolerance, this results agrees to those of former works. But simulation with BSD-c showed the opposite results. This implies the exsistence of essential differences between BSD-d patterns and BSD-c patterns.

BSD-d pattern is an essentially a pattern separation problem. It uses the discrete output values and the basic function of the network is find out the separate line of the different categories. Most of former works on fault-tolerance and generalization ability used this kind of problem, and fault-tolerant networks tends to have good performance on this kind of job because of the usage of saturated domain of the sigmoid function.

BSD-c, on the other hand, is an function-composing problem, where delicate function adjustments are required.

It is considered that this difference in the nature of the problems results in the differences found in the simulation results.

Simulation results also show that characteristics value of derivative of hidden units and smoothness of the network function does not effectively clarifies the relationship between generalization and fault-tolerance.

6 Conclusions

This thesis examined the fault-tolerance and generalization ability of multi-layer neural networks, and the relationship between these two abilities.

A new definition and measure of fault-tolerance is introduced and simulation results shows the effectiveness of these concepts.

New benchmark patterns called BSD-c and BSD-d are introduced to examine the fault-tolerance and generalization ability, and simulation results shows that depending on the nature of the problem pattern, well-known "good generalization := good fault-tolerance" equation does not always stand.

Simulation results also shows that simple network characteristics like derivative of hidden units or smoothness of the whole network function do not effectively explain the relationship between generalization and fault-tolerance.

Investigation of another network characteristics, evaluation under the multiple faults, and analysis on the nature of the continuous and discrete type of problems are left as future works.