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A Comprehensive Study of Hybrid Genetic Algorithm based Back-propagation Neural Networks

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Abstract: Artificial Neural networks are a way to solve many types of non-linear problems that are difficult to be solved through traditional techniques. Back propagation algorithm using gradient descent method is the most important approach to train the neural networks. Back propagation algorithm suffers from several disadvantages like local minima problem, slow training, and scaling problem. This paper enlightens the problems of back propagation algorithm and the ways to solve these problems by hybridizing it with Genetic algorithms.

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I. INTRODUCTION

As scientists and philosophers ponder human intelligence, several profound questions arise: what is intelligence and is it measurable, does intelligence even exist, and can it be reproduced in a machine? We immediately go to the best empirical source about what gives humans the capacity to be intelligent, the brain. While trying to classify and understand this vital organ, early researchers attempted to partition the brain into smaller pieces until they arrived at the brain cell and neurons. They found that there existed many neurons in the brain, which were all interconnected and formed a sort of network, a neural network. Artificial neural networks draw much of their inspiration from the biological nervous system. It is therefore very useful to have some knowledge of the way this system is organized.

Artificial Neural Networks: Artificial neural networks are an attempt at modeling the information processing capabilities of nervous systems. An artificial neural network is a pool of simple processing units (neurons) which communicate among themselves by means of sending analog signals. These signals travel through weighted connections between neurons. Each of these neurons accumulates the inputs it receives, producing an output according to an internal activation function [12]. Neural Networks have three building blocks- Learning Mechanism, Neural Network Architecture and Activation function. Neural network architecture is broadly classified as Single-layer feed forward network and Multi-layer feed forward network. Single-layer feed forward network comprises of two layers- Input layer to receive signals and output layer to give response. Multi-layer feed forward network comprises input layer to receive signals, hidden layer for performing intermediary computations and output layer to give response [14].

Back Propagation Algorithm: Back propagation is a systematic method of training multilayer artificial neural networks. It is built on sound mathematical base. The back propagation is a gradient descent method in which gradient of the error is calculated with respect to the weights for a given input by propagating the error backwards from output layer to hidden layer and further to input layer. This method adjusts the weights according to the error function. So, the combination of weights which minimizes the error function is considered to be a solution of the problem [13].The procedure for training a neural network through the back propagation algorithm is given below:

1. **Start**: Initialize the weights randomly.
2. **Summation:** Calculate $\sum X_i \times W_i$, where X_i denotes inputs and W_i denotes weights of neurons.
3. **Activation Function:** Apply the activation function over the summation of products of inputs and weights of corresponding neurons to obtain the forecasted output.
4. **Error Calculation**: Calculate the error at the output layer by subtracting the forecasted output from the desired output, and then finding the root mean squared error.

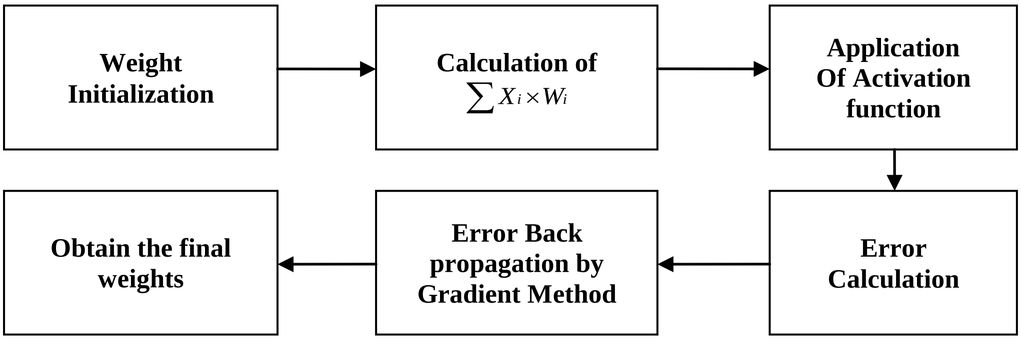

Figure 1: Steps of Back Propagation Algorithm

5. **Weight Adjustment**: Back propagate the error obtained in last step from output layer to hidden layer and then further from hidden layer to input layer to adjust the weights.
6. **Loop**: Repeat steps 2 to 5 until the error is acceptably low [12].

Genetic Algorithms: GA differs from conventional non-linear optimizing techniques as by preserving a population of the solutions, they search for better ones. The key feature of such algorithms is characterized by possessing a chromosome. A group of chromosomes is called a population. One of the genetic features is that instead of focusing on one point of the search space of a chromosome, it works on a population of chromosomes. [13]. GA encompasses three main operators: 1) selection 2) crossover and 3) mutation.

Selection operator searches according to the fitness of the members based on fitness values. In the selection operation the members of the population with better fitness can participate several times while the members with worse fitness may be deleted in order to obtain a larger fitness average. Crossover operation allows an exchange of the design characteristics between two mating parents. This operation is done by selecting two mating parents on which two random places are selected on each chromosome string and the strings between these two places among the mates are exchanged.

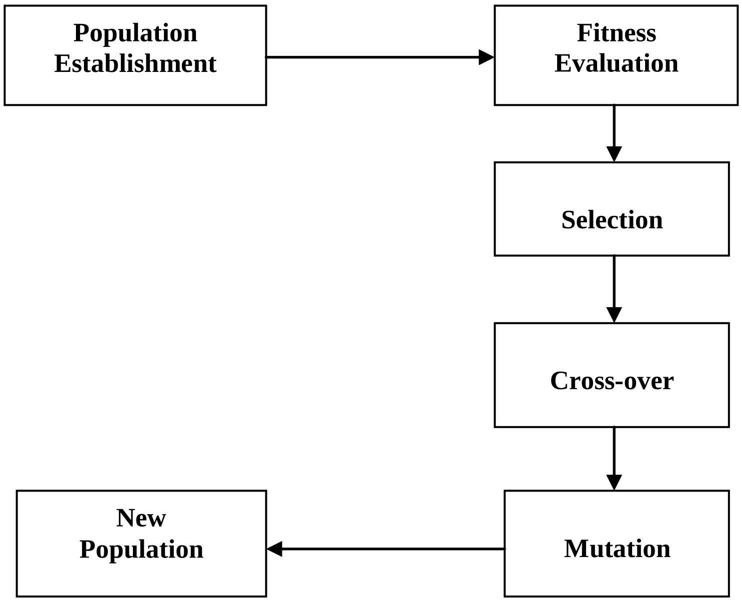

Figure 2: Steps of Genetic Algorithm

Mutation operator is another essential operator in genetic algorithm process and it acts on each chromosome after crossover operator such that a random number is produced for each bite of a chromosome, if this number is smaller than p_m, mutation will occur in that bite and otherwise it does not occur. If mutation is not applied, after crossover the offspring will enter the new generation. Mutation operation prevents losing unexpected valuable genetic information in the population during selection and crossover operation. To introduce fitness function, the variables should be put in the model and then the difference between estimated values and actual data for each individual should be calculated. In each generation the individual with minimum difference must be returned [1]. The main steps of genetic algorithms are as follows:

1. **Start**: Create the initial population of n chromosomes randomly, with each chromosome representing a set of genes.
2. **Fitness** : New Population: New population is formed by applying following operators on each chromosome present in the old population
3. **Evaluate**: The fitness of each chromosome on the basis of fitness function denoted by f(x).
   3.1 **Selection**: Select chromosome from the old population based on their fitness values f(x)
   3.2 **Recombination**: The selected chromosomes are recombined for Cross-over their properties.
   3.3 **Mutation**: Then the chromosomes are mutated to get diversity in new population.
4. **Replace**: Replace the old population with the new population obtained after application of operators.
5. **Test**: Test the problem for optimized solution.
6. **Loop**: Continue steps 2 – 5 until criterion is satisfied.

The pros and cons of genetic algorithms are as follows: genetic algorithm is a parallel stochastic optimizing algorithm. As compared with back propagation, genetic algorithm is more qualified for neural networks if only the requirement of a global searching is considered. It is good at global searching (not in one direction) and it works with a population of points instead of a single point. It is a population based search algorithm and multiple optimal solutions can be captured thereby reducing the effect to use the algorithm many times.

Secondly, genetic algorithms work with a string coding of variables instead of the variables. The advantage of working with a coding of variables is that coding makes the search space discrete even though the function may be continuous [6]. Thus, genetic algorithm requires only function values at discrete points, a discrete function can be handled with no extra cost. Also genetic algorithm can be applied to wide variety of problem. We always get the solution & the solution gets better with time.

Considering the ability of genetic algorithms to find global optima, genetic algorithms are fast, especially when tuned to the domain on which they are operating [6]. Another advantage is inherently parallel nature of genetic algorithms makes the processing faster as compared to the back propagation algorithm using gradient descent technique. In other words, the evaluation of individuals within a population can be conducted simultaneously, as in nature [1].

Another merit of genetic algorithm is that it is easy to be implemented by hardware. First of all, the required precision is not high. Second, if binary encoding is adopted, the results can be directly reflected to digital storage. Third, using genetic algorithm, the weight range can be designed according to the circuit characteristic such as the linear range of the multiplier etc. The last, the arithmetic operation is simple, which is quite favorable for hardware implementation [18].

The price one pays for genetic algorithm is its slowness. The slowness is mainly due to the slow but crucial exploration mechanisms employed, which has three basic arithmetic operators: reproduction, crossover and mutation. In addition, genetic algorithm starts searching from random genes, which will cost a lot of time [18].

Hybrid Algorithms : We can distinguish two kinds of hybridization: strong and weak hybridization. In the first one, the knowledge is included using specific operators or representations. In the latter, several algorithms are combined somehow. In this last case, an algorithm can be used to improve the results of another one separately or it can be used as an operator of the other. The hybrid algorithms that we use in this work are combinations of two algorithms (weak hybridization), where one of them acts as an operator in the other. We combine a GA with the BP algorithm (GABP), and a GA with LM (GALM).

II. LITERATURE SURVEY

McCulloch et al.(1943) in the paper entitled " A logical calculus of the ideas immanent in nervous activity " discussed that the development in the field of neural networks started with the first model of a neuron, created in 1943, had two inputs and a single output which would not activate if only one of the inputs was active[9] .

Minsky et al. (1969) in the paper entitled "Perceptrons" cleared that until the inputs summed up to a certain threshold level, the output would remain zero. This model is known today as a logic circuit. Based on this model, the first artificial neural network was designed which is called a perceptron [10].

Holland (1975) in the paper entitled "Adaptation in Natural and Artificial Systems" cleared that each generation was populated with fixed length strings which were decoded into a format that represents output. The simulated evolution of a solution through genetic algorithms was more efficient and robust than the random search, enumerative or calculus based techniques. The main reasons given in the probability of a multi-modal problem state space in non-linear problems, and that random or enumerative searches were exhaustive if the dimensions of the state space were too great [5].

Werbos (1994) found in the paper entitled "The roots of back propagation – from ordered derivatives to neural networks and political forecasting" that the actual construction of a network, as well as the determination of the number of hidden layers and the determination of the overall number of units, is a trial-and-error process, which was determined by the nature of the problem at hand. The training of the network by back propagation consists of three stages: a) The feed forward of the input training pattern, b) The calculation and back propagation of the associated error, and c) The adjustment of the weights. Three common transfer functions used in artificial neural networks are the sigmoid, linear and hyperbolic functions. Since this method required computation of the gradient of the error function at each iteration step and must guaranteed the continuity and differentiability of the error function. Unlike perceptrons which used a step function, a differentiable or continuous sigmoid activation function was used, as back propagation was a gradient descent method [20].

Srinivas et al. (1994) in the paper titled "Genetic algorithms: a survey," described the ability of genetic algorithms to find global optima, genetic algorithms were fast, especially when tuned to the domain on which they were operating. Another advantage was due to parallel nature of genetic algorithms, the evaluation of individuals within a population can be conducted simultaneously, as in nature. Another merit of genetic algorithm was easy to use [18].

Rojas (1996) proposed in the book titled "Neural Networks- a Systematic Introduction" a gradient search method for adapting the weights was developed, which were based on minimizing the root-mean squared error, known as LMS or Least Mean Squares. It was developed as a mathematical method for adapting the weights. Assuming that a desired response existed, a gradient search method was implemented, which was based on minimizing the error squared. This algorithm would later become known as LMS, or Least Mean Squares. LMS, and its variations, has been used extensively in a variety of applications, especially in the last few years. This gradient search method provided a mathematical method for finding an answer that minimized the error. Although the computational time decreased with previous work, the LMS method decreased the amount of computational time even more, which made use of perceptrons feasible. After perceptrons was published, research into neural networks went unfunded, and would remain so, until a method was developed to solve n-separable problems. Hence the most important algorithm for training multi-layered neural networks was developed known as the back propagation algorithm. It allowed neurons to be trained in a multilayer configuration. The weights were adjusted backwards, based on the error between the actual output and the desired output [14].

Thiesing et al. (1997) in the paper titled "Forecasting sales using neural networks" presented a neural network trained with the back propagation algorithm are applied to predict the future values of time series that consist of the weekly demand on items in a supermarket. The influencing indicators of prices advertising campaigns and holidays were taken into consideration. The design and implementation of a neural network forecasting system was described that had been installed as a prototype in the headquarters of a German supermarket company to support the management in the process of determining the expected sale gures. The Performance of the networks was evaluated by comparing them to two prediction techniques used in the supermarket now. [19].

Zhang et al. (1998) in the paper titled"Forecasting with artificial neural networks: the state of art" presented a state-of-the-art survey of ANN applications in forecasting with purpose to provide a synthesis of published research in this area, insights on ANN modeling issues, and the future research directions [22].

Xiaofeng (2001) in the paper entitled "The establishment of forecasting model based on BP neural networks of self-adjusted all parameters" found that the convergence of the algorithm was very sensitive to the initial value. So, it often converged to an inferior solution and got trapped in a long training time. Also, the required precision was so high that it was difficult to realize the weight storage [21].

Rajasekaran et al. (2004) described in the book entitled "Neural Networks, Fuzzy Logic and Genetic Algorithms" that the post-perception era began with the realization that adding (hidden) layers to the network could yield significant computational versatility. This yielded a considerable revival of interest in artificial neural networks which continues to this day. In the multilayered feed-forward networks, individual nodes were linked together in layers and the connections between layers were unidirectional from input to output. These were acyclic/non-recurrent in nature [12].

Rao et al. (2006) stated in the paper titled "A genetic algorithm based back propagation network for simulation of stress-strain response of ceramic-matrix-composites" that the genetic algorithms offered a number of benefits. It was observed that that Genetic algorithm is a parallel stochastic optimizing algorithm. As compared with back propagation, genetic algorithm was more qualified for neural networks if only the requirement of a global searching was considered. It was also described that GA is a population based search algorithm and multiple optimal solutions can be captured thereby reducing the effect to use the algorithm many times [13].

Azadeh et al., (2006) in the paper entitled "Integration of ANN and GA to predict electrical energy consumption" reviewed and compared merits and demerits of back propagation and genetic algorithms, efforts were made to integrate both the techniques. The hybrid techniques were applied in application areas such as electricity demand prediction, medical field, ceramic strain prediction, handwriting recognition, weather forecasting, etc. A lot of efforts have been put in the above mentioned fields for solving the problems of gradient based back propagation algorithm by hybridizing it with genetic algorithms, and the results have come out to be fruitful too[1].

Simmy et al., (2007) in the paper titled "Improving the back-propagation algorithm using evolutionary strategy" described that the back propagation algorithm changes the schematic of the perceptron by using a sigmoid function as the squashing function. Earlier versions of the perceptron used a squashing function. The advantage of the sigmoid function over the squashing function is that the sigmoid function is differentiable. This permits the back propagation algorithm to transfer the gradient information through the nonlinear squashing function, allowing the neural network to converge to a local minimum. There were some problems in the gradient based back propagation method. For one, back propagation suffered from the scaling problem. It worked well on simple training problems. However, as the problem complexity is increased, the performance of back propagation fell off rapidly because of the fact that complex spaces have nearly global minima which are sparse among the local minima. Gradient search techniques tend to get trapped at local minima. When the nearly global minima were well hidden among the local minima, back propagation could end up bouncing between local minima without much overall improvement, thus making for very slow training [16].

Frank et al. (2008) in the paper titled "Time Series Prediction and Neural Networks" stated the objective to extend the power of time-series analysis to systems with non-linear characteristics, non-linear models were proposed. The last two decades have seen the more important contributions. These were the construction and identification of state-space models, the application of artificial intelligence to the generation of data-driven rule-based models, and finally the introduction of learning techniques for model identification. The most widely used among these so-called connectionist models are neural networks that come in many different shades: static (feed-forward) networks consisting of static neurons, dynamic (feed-back) networks consisting of static neurons, static networks consisting of dynamic (differential equation) neurons, and finally, dynamic networks consisting of dynamic neurons [3].

Goldberg (2008) explained in the book titled "Genetic Algorithms in Search, Optimization and Machine learning" that the genetic algorithms are computerized search and optimization algorithm that mimic the principle of natural genetics and natural selection. Genetic algorithms perform directed random searches through a given set of alternatives to find the best alternative with respect to given criteria of fitness. Fitness is defined as a figure of merit which is to be either maximized or minimized. An initial population of chromosomes (set of strings) is taken to generate offspring (from fit parents) that competes for the survival to make up the next generation of population .The genetic operators that form the basis of simulated genetic systems are crossover, fitness proportionate reproduction and mutation. The fitness function is defined as "some measure of profit, utility, or goodness that we want to maximize". Reproduction is the first operator applied on a population for selecting good chromosome in a population for the formation of the mating pool. Crossover is the next operator to be applied over the population. Here a better offspring is produced to combine the good substring from either parent. Afterwards mutation is applied. It is used to change one of the elements of substring with a small probability to keep the diversity of population. After the application of all the three operators, a next set of chromosomes i.e. new population of individuals is obtained which is further used to find the fitness. This process continues till the stopping criterion is met. Successive generation of chromosome improve in quality provided that the criteria used for survival is appropriate. This process is referred to as Darwinian natural selection or survival of the fittest [4].

Mathur et al., (2008) in the paper titled "Offline handwriting recognition using genetic programming" found that the genetic algorithms work with a string coding of variables instead of the variables. The advantage of working with a coding of variables is that coding makes the search space discrete even though the function may be continuous. Thus, genetic algorithm requires only function values at discrete points, a discrete function can be handled with no extra cost. Also genetic algorithm can be applied to wide variety of problem. We always get the solution & the solution gets better with time [8].

Huawang et al. (2009) in the paper titled "Application of an improved genetic algorithm in artificial neural networks" found that the selection of number of hidden nodes in the network was a problem. If the number of hidden neurons was small, then the function to be learnt might not be possibly represented as the capacity of network was small. When the number of hidden neurons was increased, the number of independent variables of the error function also increases along with the rapid increase in the computing time [6].

Sarangil et al.(2009) in the paper entitled "Short term load forecasting using artificial neural network: a comparison with genetic algorithm implementation" discussed the different stages of during the process of training (a) The feed forward of the input training pattern, (b) The calculation and back propagation of the associated error, and (c) The adjustment of the weights. Three common transfer functions used in artificial neural networks were the sigmoid, linear and hyperbolic functions. Since this method requires computation of the gradient of the error function at each iteration step, we must guarantee the continuity and differentiability of the error function. Unlike perceptrons which used a step function, a differentiable or continuous sigmoid activation function was used, as back propagation was a gradient descent method. It was also analyzed that one of the most popular activation functions for back propagation networks is the sigmoid, a real function [15].

Karegowda et al. (2011) proposed in the paper titled "Application of Genetic Algorithm Optimized Neural Network Connection Weights for Medical Diagnosis of PIMA Indians Diabetes" that model selection for a neural network entails various factors such as selection of the optimal number of hidden nodes, selection of the relevant input variables and selection of optimal connection weights. This paper presents the application of hybrid model that integrates genetic algorithm and back propagation network where GA is used to initialize and optimize the connection weights of BPN. Significant features identified by using two methods, Decision tree and GA-CFS method, are used as input to the hybrid model to diagnose diabetes mellitus. The results prove that, GA-optimized BPN approach has outperformed the BPN approach without GA optimization. In addition the hybrid GA-BPN with relevant inputs lead to further improvised categorization accuracy compared to results produced by GA-BPN alone with some redundant inputs [7].

Farahat et al. (2012) proposed in the paper titled "Short-Term Load Forecasting Using Curve Fitting Prediction Optimized by Genetic Algorithms" that the curve fitting prediction and time series models are used for hourly loads forecasting of the week days. The curve fitting prediction (CFP) technique combined with genetic algorithms (GAs) is used for obtaining the optimum parameters of Gaussian model to obtain a minimum error between actual and forecasted load. A new technique for selecting the training vectors is introduced. The proposed model is simple, fast, and accurate. It is shown that the proposed approach provide very accurate hourly load forecast. Also it is shown that the proposed method can provide more accurate results than the conventional techniques [2].

Peralta et al.(2013) in the paper titled "Time series forecasting by evolving artificial neural network using genetic algorithms and differential evaluation and estimation of distribution algorithm " evaluated two methods to evolve neural networks architectures, one carried out with genetic algorithm and a second one carry out with differential evolution algorithm. A comparative study between these two methods, with a set of referenced time series will be shown. The object of this study was to try to improve the final forecasting getting an accurate system [11].

Singh et al.(2014) described in the paper titled "Temporal Weather Prediction using Back Propagation based Genetic Algorithm Technique" that weather parameters were assumed to be independent of each other in the hybrid back propagation based genetic algorithm approach and their temporal relation with one another was not considered. It was the major drawback of hybrid BP/GA approach. Hence time series based hybrid BP/GA technique outperformed the previous models while performing for dynamic and chaotic weather conditions [17].

III. CONCLUSION

This research article discusses a number of applications where back propagation algorithm, genetic algorithms, and hybrid BP/GA algorithms are used. It is found during the survey that genetic algorithms are more efficient and robust than the random search, enumerative or calculus based techniques. The genetic algorithms are fast, especially when tuned to the domain on which they were operating. Another advantage is due to parallel nature of genetic algorithms, the evaluation of individuals within a population can be conducted simultaneously, as in nature. Moreover, genetic algorithms are easy to use. The hybrid techniques can learn efficiently by combining the strengths of BP with GA and hence, are more qualified for neural networks if only the requirement of global search is considered. Thus, the use of hybrid genetic based back propagation technique is suggested for real time forecasting and pattern recognition applications.

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