BULGARIAN ACADEMY OF SCIENCES

INSTITUTE OF INFORMATION AND COMMUNICATION TECHNOLOGIES

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TIME SERIES FORECASTING WITH ARTIFICIAL NEURAL NETWORKS

ABSTRACT OF PhD THESIS

Supervisor:

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Sofia, 2022

The dissertation was discussed and admitted to the defense at an extended session of the Department of “Information processes and decision support systems” at IICT-BAS, which had been held on 12.04.2022.

The dissertation is structured in an introduction, a presentation of four chapters, a conclusion, a declaration of originality of the results, a list of publications on the dissertation and a bibliography. The dissertation is in the volume of 157 pages, 68 figures and 4 tables, 134 cited literary source and 1 application.

The defense of the dissertation will take place on ……. from …… hours in the hall …… of the block …… of IICT-BAS at an open meeting of the scientific jury consisting of:

1. Prof. Milena Lazarova-Mitseva, PhD – TU-Sofia
2. Prof. Kosta Boshnakov, PhD – UCTM
3. Prof. Velislava Lyubenova, D.Sc. – IR-BAS
4. Assoc. Prof. Tatiana Atanasova, PhD – IICT-BAS
5. Prof. Dimitar Karastoyanov, PhD – IICT-BAS

Reserve members:
1. Assoc. Prof. Katia Rasheva-Yordanova, PhD – UNIBIT
2. Assoc. Prof. Leoneed Kirilov, PhD – IICT-BAS

The materials on the defense are available to those interested in the room ……... of IICT-BAS, Acad. Georgi Bonchev Str., bl. 2

Author: Petar Rosenov Tomov
Title: Time Series Forecasting with Artificial Neural Networks

Introduction

In everyday life, a person encounters many different time series, representing discrete random variables arranged in chronological order. Typical examples are the average daily temperatures, the quantities of fuels sold during the year, the values of the currencies on the financial markets and others. Such phenomena are observed in almost all areas of human activity and therefore they are the subject of study and forecasting.

Artificial neural networks have become extremely popular in the last five decades. Their main advantage is the ability to reproduce nonlinear dependencies using sample data. They are used as a tool for classification, image recognition and forecasting. In the most common variant, artificial neural networks are directed weight graphs. The organization is layered, with information transmitted from the input layer to the output layer. Most often, the nodes between the individual layers are fully connected, which means that each node is connected to all other nodes in the adjacent layer. The organization of the number of layers and how many nodes to have in each layer is subject to empirical determination and strongly depends on the nature of the problem. The learning process is most often with training examples (teacher training) and the goal is to achieve such an optimal value for the weights on the edges of the graph, so that the artificial neural network performs the calculations for which it is intended. Once trained, artificial neural networks are extremely fast-acting. This characteristic makes them especially desirable in many industrial technical solutions. Difficulties in using artificial neural networks are related to the time required for their training. Over the decades, many different algorithms have been developed to search for optimal weights in the network. The two main directions of algorithms are gradient (exact numerical algorithms) and heuristic (most often stochastic with introduced empirical rules). Accelerating the learning process is a major problem in the practical use of artificial neural networks.

Purpose and tasks

The aim of this dissertation is to propose hybrid algorithms for accelerating learning in artificial neural networks of the multilayer perceptron type for the purpose of time series forecasting. To achieve this goal it is necessary to perform the following tasks:

- To make an overview analysis and classification of algorithms for training of artificial neural networks of multilayer perceptron type;
- To analyze the possibility of combining different algorithms for the implementation of hybrid training of artificial neural networks of the multilayer perceptron type;
- To propose algorithms for training of artificial neural networks of multilayer perceptron type in distributed environment;
- To propose an improvement in order to reduce the training time of artificial neural networks of the multilayer perceptron type;
- To propose a software architecture for the implementation of mobile distributed forecasting calculations;
- To make program implementation of the proposed hybrid algorithms for training of artificial neural networks of multilayer perceptron type in order to prove their operability;
- To make a comparative analysis of the effectiveness of the known algorithms for training artificial neural networks of the multilayer perceptron type.

Structure of the dissertation

The dissertation is structured in an introduction, a presentation of four chapters, a conclusion, a declaration of originality of the results, a list of publications on the dissertation and a bibliography. The dissertation is in the volume of 157 pages, 68 figures and 4 tables, 134 cited literary source and 1 application.

The **introduction** clarifies the relevance of the problem and presents the

structure, object, subject, goals and objectives.

The **first chapter** provides an overview analysis and classification of widely used algorithms for training artificial neural networks. The advantages and disadvantages of exact numerical algorithms and heuristic algorithms are determined. The possibilities for training of artificial neural networks in sequential calculations, parallel calculations and calculations in a distributed environment are presented.

The **second chapter** presents the theory of algorithms in the training of artificial neural networks of the multilayer perceptron type. Modifications of some of the algorithms that are applicable in time series forecasting are proposed. The applied modifications refer to: 1) determination of weights, using a genetic algorithm using the operations - selection, crossing and mutation. A new selection operator has been proposed and analyzed, based on the creation of generations in a recursive descent procedure. The speed of the used heuristic algorithms was studied experimentally; 2) approximation of curves to multiple points - for incremental approximation of time series the equation of lines and a line of sine functions are used. An approach for calculating the coefficients of sine functions with an optimizer based on the evolution of differences and a swarm of particles is proposed; 3) training on an artificial neural network - an extensive model of training is presented, which aims to find optimal weights for a network of three-layer perceptron; 4) the activation function in artificial neural networks - an alternative to a derivative for the activation function in artificial neural networks is proposed. An essential feature of the proposed function is that it shows promising results in terms of speed and accuracy. For the purpose of numerical testing of the proposed modifications, classification according to the frequency of voting for each user and the success rate of each vote cast is required. The solution of this specific task was realized through the use of self-organizing Kohonen maps.

The **third chapter** presents a software architecture that allows the implementation of selected algorithms and proposed modifications. An object-oriented model, a relational model, communication protocols and a graphical user interface are proposed for the realization of the software architecture. All of them based on

appropriate data structures.

The **fourth chapter** presents a comparative analysis of some accurate numerical and heuristic algorithms. The performed experiments and the obtained results are described. Their productivity and total error are analyzed.

In the **conclusion** a summary of the performed researches is made. Some guidelines for future research related to the application of artificial neural networks are also provided.

Chapter 1 Forecasting time series using machine self-learning

The first chapter provides an overview of the most commonly used ways to predict time series and how machine self-learning is applied in this problem area. Making forecasts is of great importance for modern societies. Starting with the forecast for the meteorological situation and ending with forecasts for the change in prices for goods, stocks and currencies. In the case of price forecasting, the data are successfully presented in the form of a time series. Quite logically, each subsequent value should have some dependence on the previous values. Many ways to predict financial time series have been developed in recent decades, but artificial neural networks stand out as one of the most promising. Characteristic of artificial neural networks is that they are a very effective tool once trained. The learning process, on the other hand, often takes too long and requires a large amount of computing resources. One of the most widely used ways to train artificial neural networks is the backpropagation algorithm. This algorithm belongs to the group of exact numerical, gradient methods. Its weaknesses are the inability to be effectively realized in parallel calculations and its tendency to fall into local optimums without effective ways to avoid them. The error backpropagation algorithm is very well complemented by heuristic, evolutionary global optimization algorithms. The characteristic of this type of heuristics is that they lend themselves to an extremely high degree of parallel processing. Some of these heuristics are specifically designed to avoid local optimums. The wide possibilities for

parallel processing in evolutionary and population heuristics allow their realization on heterogeneous systems for distributed computations. In order to be more financially efficient, this type of distributed calculation can be performed on the principles of donated computing power. The presence of significantly more mobile devices (smartphones and tablets) compared to desktop computer systems leads to motivation to perform calculations in the form of mobile distributed calculations.

A summary of the characteristics of the exact numerical and heuristic teaching methods is made, considered in the review part.

Main conclusions to Chapter 1:

All of the above gives reason to seek the implementation of a mobile distributed computing system that trains artificial neural networks, with a hybrid algorithm (error propagation and population global optimization) to predict financial time series.

Chapter 2 Algorithms for forecasting and training of ANN

The second chapter presents author's algorithms. Possibilities for improving the selection algorithm in genetic algorithms have been studied. The idea of recursive descent into nodes of tree structure is applied, as each node is characterized by a sub-population. In each node, complete depletion is performed for recombination of individuals in the adjacent node under a population, calculating the target function (Table 2.2).

	Michalewicz	Ackley	Schwefel	Rastrigin	Griewank
Local Search	1062492546	531027435	533232986	507650704	592370933
Brute-Force	403141211	166733879	175069174	159862955	218428047

Table 2.1 Time spent in milliseconds

	Michalewicz	Ackley	Schwefel	Rastrigin	Griewank
Local Search	641125639	641024362	640914978	641092606	640830762
Brute-Force	235794757	235794757	235794757	235794757	235794757

Table 2.2 Number of calculations of the objective function

	Michalewicz	Ackley	Schwefel
Local Search	-1484.7137949531716	21.09334816052046	3877924.0971615044
Brute-Force	-1439.2296970724608	21.114702255301292	3919318.729777085
	Rastrigin	Griewank	
Local Search	170204.87849875208	259918.15469527297	
Brute-Force	171780.33307271387	262621.61053178157	

Table 2.3 Achieved suboptimal values

Complete depletion is also combined with local search, in order to further improve (Table 2.1) the results (Table 2.3) in the specific node. The achieved results are presented in (Tomov-01, Tomov-02). In the publication (Tomov-01) the author of this dissertation has 1/3 contribution, which consists in proposing the presented idea and writing the program code for the experiments, which is why he is the leading author in the publication. In the publication (Tomov-02) the author of the present dissertation has 1/3 contribution, which consists in proposing the presented idea and writing the program code for the experiments, which is why he is the leading author in the publication.

The possibilities for fitting curves to multiple points with the help of an equation for lines and a series of sine functions have been studied. The achieved curve is used to generate a forecast (Fig. 2.4), outside the range of known measured points. The achieved results are presented in (Velichkova-01). In a publication (Velichkova-01) the author of this dissertation has 1/3 contribution, which consists in proposing the presented idea. The possibilities for rapid prototyping of artificial neural networks with

the help of a swarm of particles and the evolution of differences have been studied. The achieved results are presented in (Tomov-04).

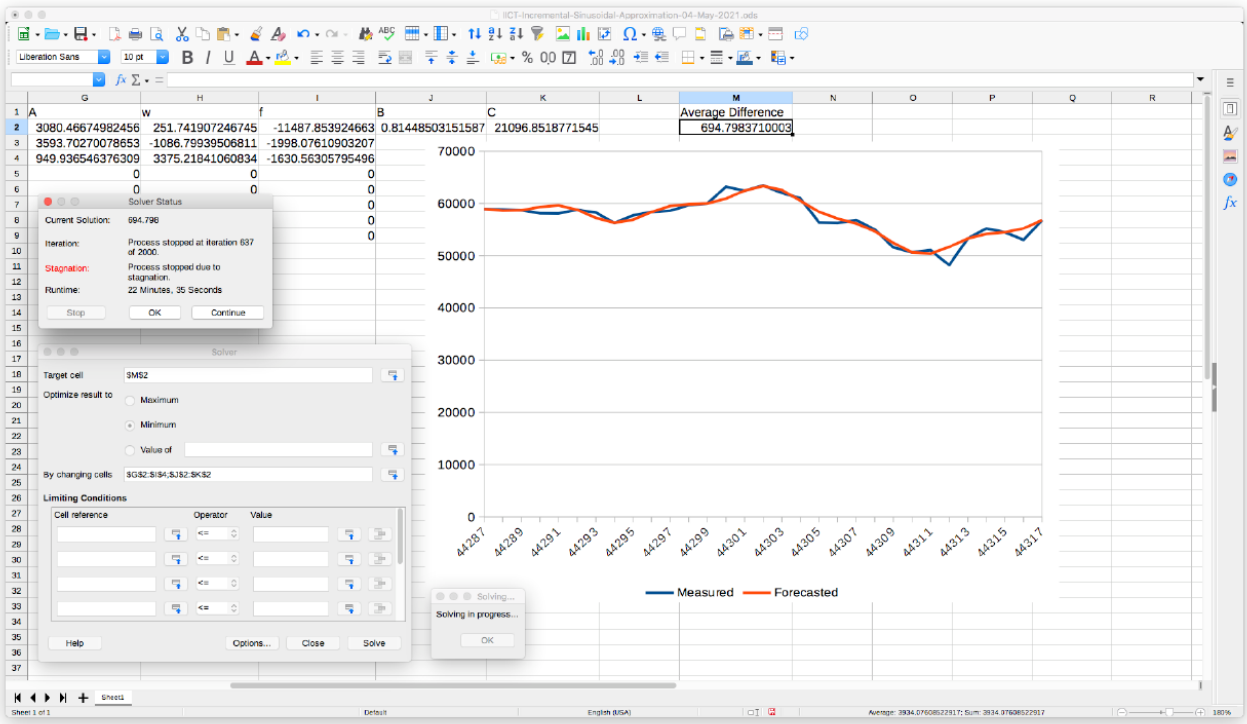


Fig. 2.4 Approximation with lines and sine functions

An alternative to the first derivative of the periodic attenuating sinusoid for activation function in artificial neural networks has been proposed. When the activation function has a periodic component, this also affects its first derivative. The periodic component and both breakpoints lead to a delay in the learning process. As a result of these two complications, backpropagation training leads to a slower convergence of the algorithm. An elegant approach to speed up the process is to replace the first derivative with a function similar in shape but without a periodic component and without breakpoints f (x) = exp ($-x^2$). A comparison is made between the proposed alternative function and the first derivative of the periodic decaying sine wave as an activation function. The alternative function gives better results in terms of speed and error (Fig. 2.5 and Fig. 2.6).

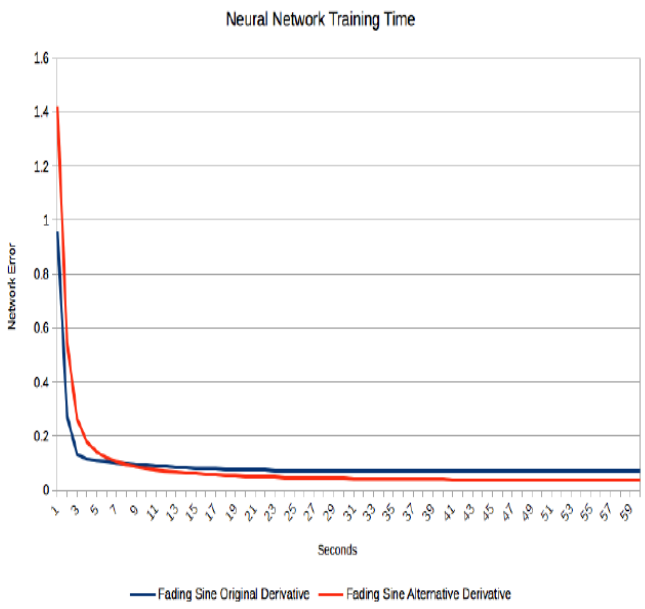


Fig. 2.5 Error made by the network

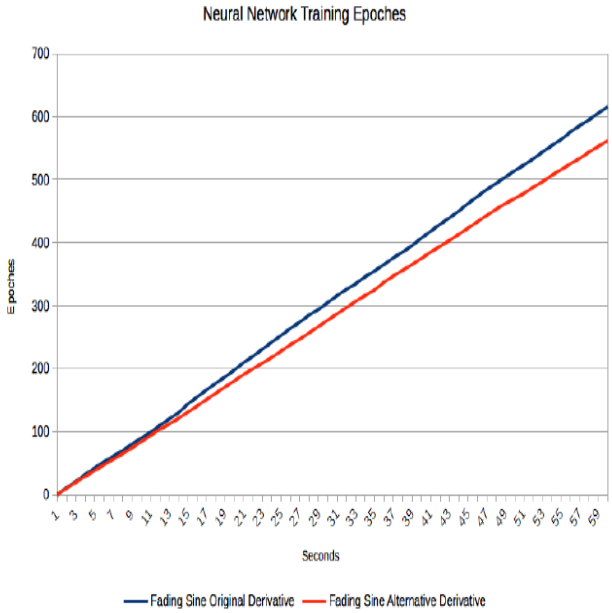


Fig. 2.6 Number of epochs

A study of the possibilities for classifying consumer votes in forecasting financial time series has been performed. When developing a system for collecting consumer votes, the classification of the collected data is essential. In order for users' votes to be used for future forecasting, the information collected must be classified according to the frequency of voting per user and the success rate of each vote cast. This task is effectively solved with self-organizing Kohonen maps. The achieved results (Fig. 2.7) are presented in (Tomov-03). In the publication (Tomov-03) the author of the present dissertation has 1/3 contribution, which consists in proposing the presented idea and writing the program code for performing the experiments, which is why he is the leading author in the publication.

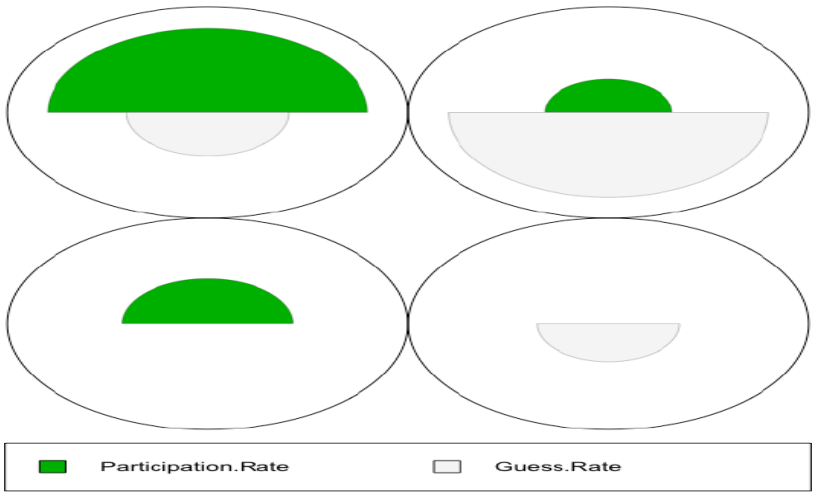


Fig. 2.7 Four groups by frequency of participation and level of knowledge

Main conclusions to Chapter 2:

a) Proposed improvements in the selection operation in genetic algorithms can improve the search for suboptimal solutions, although this is at the expense of computational time;

b) The generalizing possibilities of sinusoidal approximation give sufficient grounds for this tool to find application in the practical forecasting of financial time series;

c) Rapid prototypes of artificial neural networks are possible with the available optimization tools in spreadsheet software packages;

d) Alternatives to derivatives in artificial neural networks can speed up the learning process;

e) Slowly calculated target functions significantly slow down the process of finding suboptimal solutions;

f) Classification of consumer vote in human-computer distributed calculations is a key component for generating forecasts.

Chapter 3. Software system for forecasting with ANN of time series

The third chapter presents the architecture (Fig. 3.1) and software implementation of a distributed system in mobile forecasting devices.

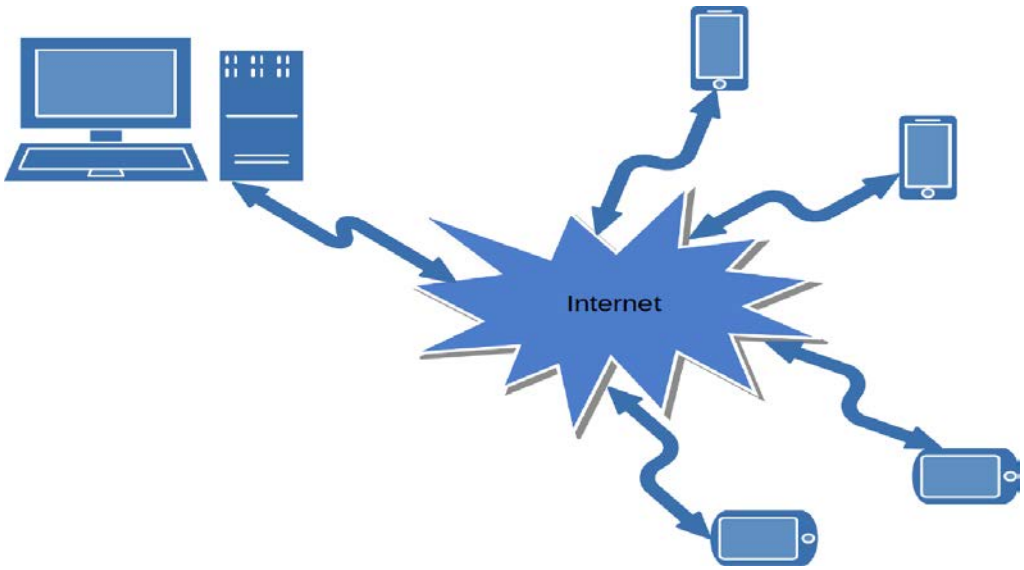


Fig. 3.1 System architecture

A software solution for mobile devices has been developed under the Android OS operating system (Fig. 3.2).

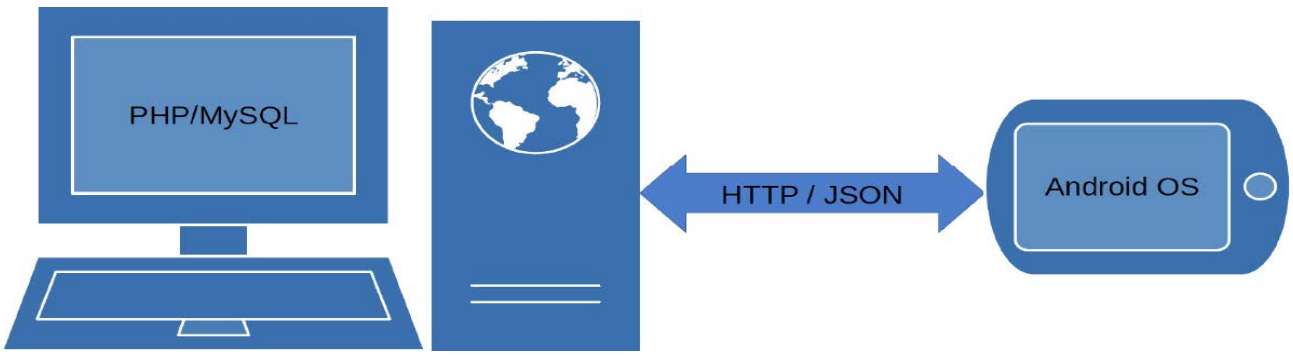


Fig. 3.2 Mobile application

The developed program code is presented as a subsystem of client-server type. In turn, the mobile application is presented with a modular architecture (Fig. 3.3) for maximum configurability.

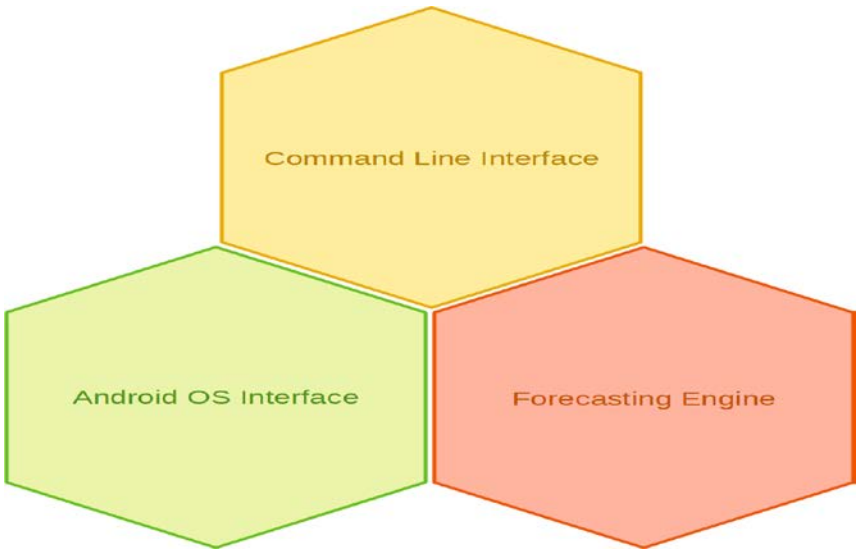


Fig. 3.3 Modular organization

A presentation of the developed graphical user interface was also made (Fig. 3.4). The external program libraries included in the forecast calculation processes are presented (Fig. 3.5).

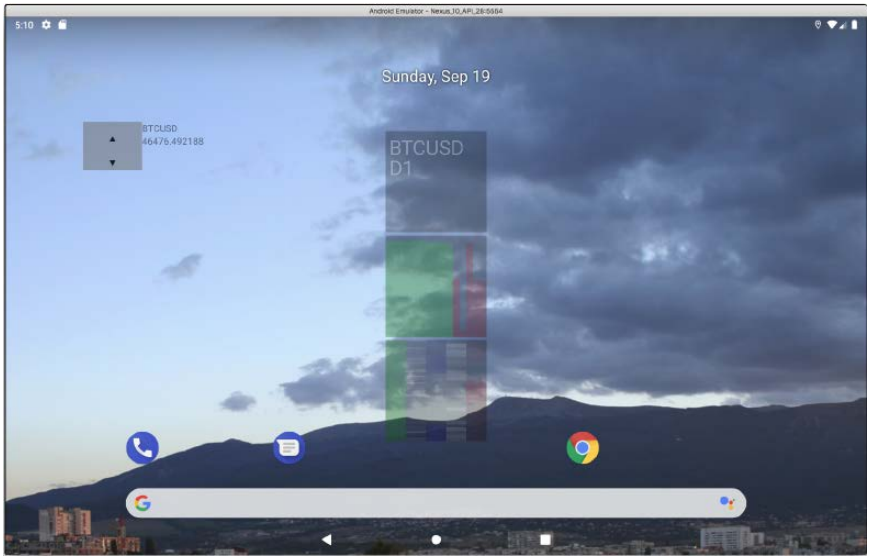


Fig. 3.4 Graphical User Interface

The user has the opportunity to see the currency pair for which the forecast was made, the learning process of the ANN and the result (forecast value) of the trained neural network. The interface also allows collecting the user's subjective opinion on

how he expects the price of the respective currency pair to change. The external program libraries included in the forecast calculation processes are presented (Fig. 3.5).

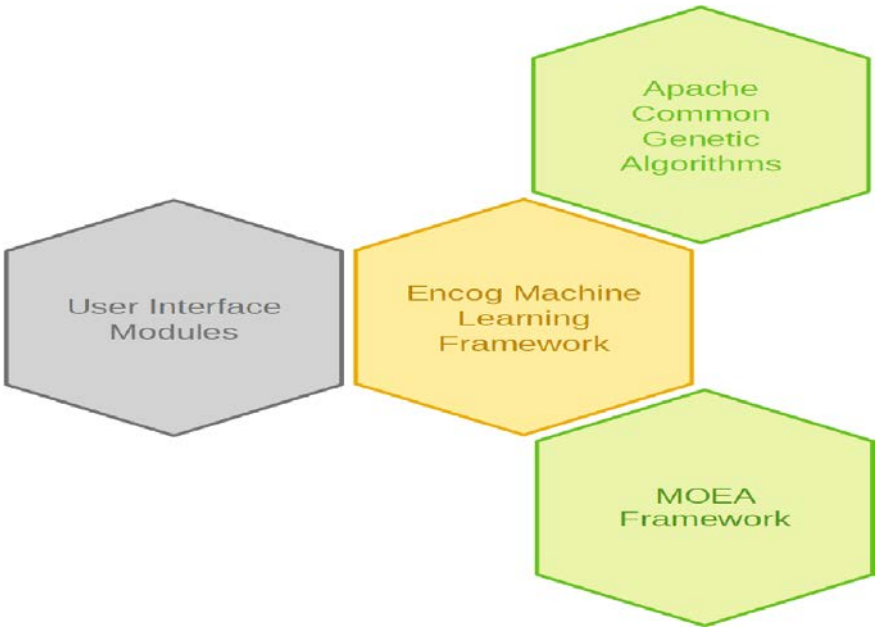


Fig. 3.5 External program libraries

The results obtained are presented in (Tomov-05, Tomov-06, Tomov-07, Zankinski-02). In the publication (Tomov-05) the author of this dissertation has 1/3 contribution, which consists in proposing the presented idea and writing the program code for the experiments, which is why he is the leading author in the publication. In the publication (Tomov-06) the author of the present dissertation has 1/3 contribution, which consists in proposing the presented idea and writing the program code for the experiments, which is why he is the leading author in the publication. In the publication (Tomov-07) the author of this dissertation has 1/3 contribution, which consists in proposing the presented idea and writing the program code for the experiments, which is why he is the leading author in the publication. In the publication (Zankinski-02) the author of the present dissertation has 1/3 contribution, which consists in writing the program code for performing the experiments.

Main conclusions to Chapter 3:

a) The distributed computing architecture with mobile devices can be extremely effective in solving practical problems;

b) The modular organization of the software in mobile applications gives a high degree of flexibility in solving technological tasks;

c) The graphical user interface is key to user satisfaction when participating in projects with donated computing power;

d) The efficient separation of the calculation modules from the graphical user interface modules allows for effective quality control;

e) The use of open source software libraries significantly shortens software production time and improves quality by relying on the active community of software library maintenance community.

Chapter 4 Numerical tests of algorithms in the forecasting system

In the fourth chapter a comparative analysis of the selected exact numerical methods and heuristic methods for training artificial neural networks is performed. The basic form of the time series, the next sine function and the complex form of the time series from the price of the digital currency bitcoin were used as input data.

The tested exact numerical algorithms are:

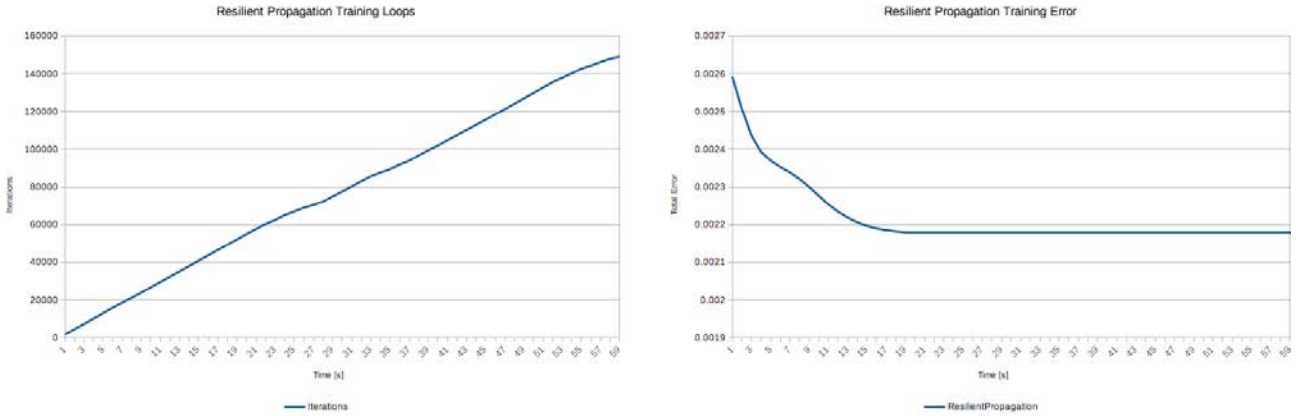
- Backpropagation;
- ResilientPropagation;
- QuickPropagation;
- ScaledConjugateGradient;
- ManhattanPropagation.

The tested heuristic algorithms are:

- Evolution Strategy;
- Genetic Algorithm;
- Deferential Evolution.

For each algorithm, a graphical representation of the number of training cycles and the total error made by the ANN was made.

With the exact numerical methods, the algorithm for learning with error backpropagation is clearly distinguished (Fig. 4.1).



(а) Брой тренировъчни цикли (б) Обща грешка допусната от ИНМ

Fig. 4.1 Resilient Propagation

In heuristic methods, genetic algorithms show good results (Fig. 4.2). The results obtained are presented in (Tomov-08).

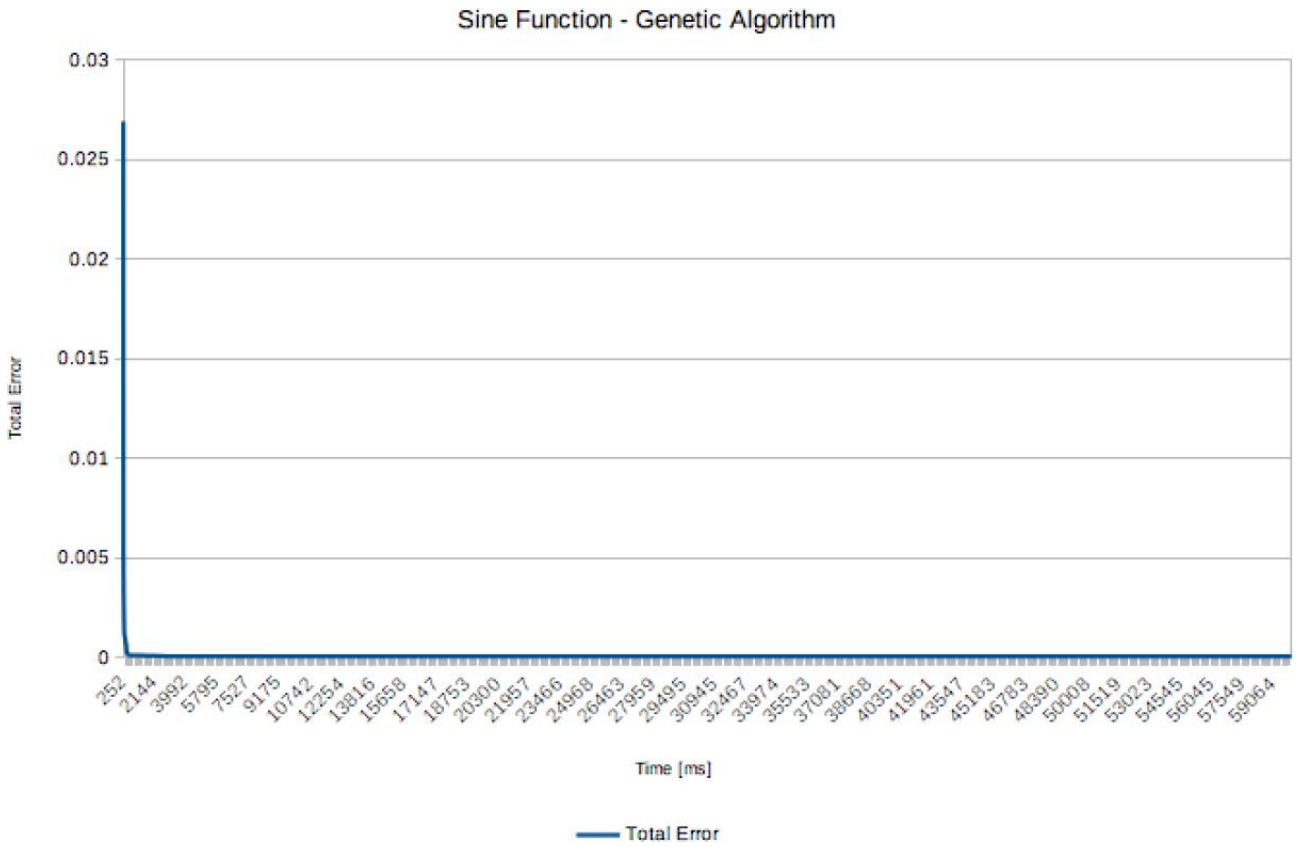


Fig. 4.2 Efficiency of genetic algorithms

Main conclusions to Chapter 4:

a) Accurate numerical methods are extremely effectively combined with stochastic optimization algorithms in the training of artificial neural networks;

b) The open format in which the list of accurate and stochastic algorithms are organized allows for rapid and efficient expansion of this list of algorithms;

Conclusion – summary of the obtained results

The obtained results, described in the present dissertation, can be summarized in the following scientific and applied scientific contributions / results:

1. A review analysis and classification of algorithms for training of artificial neural networks of the multilayer perceptron type has been made. The most used ways of forecasting time series and how machine self-learning is applied in this problem area are discussed. It has been found that the

backpropagation algorithm, which belongs to the group of exact numerical, gradient algorithms, is the most commonly used for training artificial neural networks. It has also been found that this algorithm complements very well with the heuristic, evolutionary algorithms for global optimization, which in turn lend themselves to an extremely high degree of parallel processing;

2. For the purposes of the ANN training process, a genetic algorithm that relies on operations such as selection, crossbreeding and mutation has been proposed in determining weights. Therefore, a new selection operator has been proposed, based on the creation of generations in a recursive descent procedure, which provides the desired speed of the used heuristic algorithms;
3. The incremental approximation of time series is most often realized by the equation of lines and a line of sine functions. To achieve a better approximation, an approach for calculating the coefficients of the sine functions with an optimizer based on the evolution of differences and a swarm of particles is proposed;
4. An alternative derivative to the activation function in artificial neural networks is proposed. The results obtained show better speed and error in favor of the proposed alternative function than when using the first derivative of a periodic attenuation activation function;
5. A genetic algorithm for training artificial neural networks of the multilayer perceptron type in a distributed environment has been proposed, which makes it possible to use it in parallel processing;
6. A software architecture is proposed, allowing the implementation of mobile distributed computing, based on the proposed hybrid algorithms. The software implementation for hybrid use of gradient numerical and heuristic algorithms for weight optimization in artificial neural networks is implemented in a mobile application for Android.

Guidelines for Future Research

Achieving in the Android operating system could be a similar goal to achieve in the iOS operating system of Apple. Unlike Android, iOS is a completely closed operating system. The iOS application distribution model would also lead to additional difficulties. Another direction for the development of the ideas from the dissertation is oriented to the KaiOS operating system. This operating system is not yet widespread and is aimed primarily at less powerful mobile devices, but can be a very productive direction for further research.

Regarding the algorithms and software libraries used, there are many possibilities to improve the existing algorithms and add new ones. The software libraries used are open source, which gives great freedom to study the program code, add it and optimize it, as well as expand it with new algorithms.

Some of the areas with potential application of artificial neural networks are management of autonomous systems, forecasting the workload of employees, forecasting the presence of employees in the office, when conducting a population census and others. Some of these potential applications are also targeted by some future research.

Approbation of results and publications

The main results obtained in the development of the dissertation are reported in eleven publications in specialized journals, national and international conferences:

1. Mateeva, G., Tomov, P., Parvanov, D., Petrov, P., Kostadinov, G., Balabanov, T.: Some Capabilities of Android OS for Distributed Computing. Proceedings of Big Data, Knowledge and Control Systems Engineering BdKCSE’21, 2021, 1-6, ISBN 978-1-6654-1043-4.

2. Zankinski, I., Barova, M., Tomov, P.: Hybrid Approach Based on Combination of Backpropagation and Evolutionary Algorithms for Artificial Neural Networks Training by Using Mobile Devices in Distributed Computing Environment. Proceedings of 11th International Conference on Large-Scale Scientific Computations LSSC'17, June 5-9, 2017, Sozopol, Bulgaria, 2017, 425-434, ISBN 978-3-319-73440-8.

3. Tomov, P.: Encog Gradient Training Algorithms Evaluation. Problems of Engineering Cybernetics and Robotics, vol. 77, 2021, 11-19, ISSN 2738-7356.

4. Tomov, P.: Multilayer Perceptron Fast Prototyping with Differential Evolution and Particle Swarm Optimization in LibreOffice Calc. Problems of Engineering Cybernetics and Robotics, vol. 75, 2021, 5-14, ISSN 2738-7356.

5. Tomov, P., Zankinski, I., Balabanov, T.: Training of Artificial Neural Networks for Financial Time Series Forecasting in Android Service and Widgets. Problems of Engineering Cybernetics and Robotics, no. 71, Institute of Information and Communication Technologies - Bulgarian Academy of Sciences, 2019, 50-56, ISSN 1314-409X.

6. Tomov, P., Zankinski, I., Balabanov, T.: Server Side Vote Clustering in Human-Computer Distributed Computing. Information Technologies and Control, no. 2, John Atanasoff Society of Automatics and Informatics, 2019, 15-19, ISSN 2367-5357.

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The results achieved in the dissertation were awarded a prize in a competition for global scalable optimization, held as part of the International Conference on High Performance Computing, 2019.

Declaration of Originality

Hereby, I declare that I have composed the presented thesis independently on my own and without any other resources than the ones indicated. All thoughts taken directly or indirectly from external sources are properly denoted as such.

This work has neither been previously submitted to another authority nor has it been published yet.

Signature:……

Acknowledgments

I would like to express my sincere gratitude and appreciation to my supervisor Prof. Vladimir Monov, Ph.D. and to Prof. Daniela Borissova, D.Sc., for their valuable guidance, professional competence and assistance in the preparation of this thesis.

I would also like to thank to my colleagues Senior Research Associate Todor Balabanov, PhD and Eng. Ilian Zankinski, with whom we have worked together throughout most of the research, for their help and assistance.

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