REVIEW

by Assoc. Prof. Dr. Tatiana Vladimirova Atanasova - Institute of
Information and Communication Technologies - BAS
member of a Scientific Jury appointed by Order of the Director of IICT-BAS
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ABOUT: Dissertation work of **Petar Rosenov Tomov** on "TIME SERIES FORECASTING WITH ARTIFICIAL NEURAL NETWORKS ", presented for obtaining the educational and scientific degree "Doctor" in the doctoral program " Communication Networks and Systems", professional field 5.3 "Communication and Computer Engineering" with scientific supervisor: Prof. Dr. Vladimir Vassilev Monov.

1. General description

At the first meeting of the Scientific Jury I was chosen to write a review and received the following documents:

- dissertation
- abstract in Bulgarian and abstract in English
- reference on the implementation of the minimum requirements of ICT
- list of printed scientific publications on the topic of the dissertation
- publications on the topic of the dissertation in full text.

2. Relevance, aim and tasks

The topic of the dissertation is in the field of modern methods for training artificial neural networks for predicting time series, which can be represented as numerical and symbolic sequences. Forecasting future values of time series, resulting from the measurement of both technical characteristics and natural, social and economic parameters in various fields of human activity, is invariably a current research area. Among the many forecasting tools, one of the most innovative approaches is the use of artificial neural networks (ANNs). The adjustment of the weights in the ANN is a numerical optimization task and there are many algorithms proposed for finding the optimal solution. In this regard, the dissertation applies new algorithms and approaches for training ANN to solve various optimization problems of theory (calculation of various mathematical functions to test heuristic optimization algorithms) and practice (two-dimensional cutting, forecasting).

The **aim** of the present dissertation includes the development of hybrid algorithms for accelerating learning in artificial neural networks of the multilayer perceptron type for time series prediction.

To achieve the goal of the dissertation the following **research tasks** are formulated:

1. To make an overview analysis and classification of algorithms for training of artificial neural networks of multilayer perceptron type;
2. To analyze the possibility of combining different algorithms for the implementation of hybrid training of artificial neural networks of the multilayer perceptron type;
3. To propose algorithms for training of artificial neural networks of multilayer perceptron type in distributed environment;
4. To propose an improvement in order to reduce the training time of artificial neural networks of the multilayer perceptron type;
5. To propose a software architecture for the implementation of mobile distributed forecasting calculations;
6. 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;
7. To make a comparative analysis of the effectiveness of the known algorithms for training artificial neural networks.

3. General characteristics of the dissertation

The dissertation consists of 168 pages, structured in an introduction, four chapters, a conclusion, a bibliography and an appendix with program code. It contains 68 figures, 4 tables, 25 listings and 134 literature sources. Lists of abbreviations, figures, tables and listings are presented.

Chapter one provides a synthesized overview of existing methods for finding predicted values in time series with an emphasis on neural networks and heuristic algorithms. The need to look for new methods for training neural networks and ways to organize calculations in a distributed environment is justified. It is noted that numerous algorithms have been developed for the training of ANN. Their diversity is determined by the different types of tasks and data for which they are intended. This summary is well illustrated in section 1.2 of the first chapter. The need to develop new training algorithms aimed at specific types and structures of data is justified.

The **second chapter** presents the essential part of the dissertation, it offers:

- New operator for selection in the genetic algorithm for training of ANN with realization of recursive descent on nodes of tree-like

structure of populations in combination with local search of the best individuals.

- Investigation of the approximating properties of ANN for extrapolation of time series to generate the forecast by optimizing the coefficients of the joint use of sinusoidal and linear equations with the evolution of differences and swarms of particles.
- Deployed model for learning the ANN in the LibreOffice Calc software package in the two-dimensional plane of cells.
- Replacing a derivative of an activation function during ANN training with another type of dependence.
- Approach to the implementation of slow computational functions with genetic algorithms in a distributed environment.
- Analysis of the classification properties of ANN of the type of self-organizing Kohonen maps in the organization of calculations in a distributed environment.

The results of the second chapter are published in 5 articles.

I note the heuristic approach to choosing a substitute function (Fig. 2.2) when teaching the ANN as original. I suspect that future research could focus on more rigorous mathematical proof of the proposed approach.

An interesting solution for the implementation of slowly computable functions in a distributed environment with a clear visualization of intermediate states in NP optimization for two-dimensional cutting is also proposed.

The **third chapter** describes the software architecture for ensuring the implementation of the developed approaches for training of ANN for time series. The real results of the conducted tests are shown, proving the successful solution of the set tasks.

The results of the third chapter are published in 5 articles.

The material from the **fourth chapter** is more logically connected with the first, in which an overview and comparative analysis of accurate numerical and heuristic algorithms for learning is made.

The results of the fourth chapter are published in 1 article.

Various programming languages (R, Python, Java, PHP, etc.) and software tools and libraries (LibreOffice Calc, Encog, etc.) were used in the research in the dissertation.

4. Contributions

I accept and positively evaluate the scientific and applied contributions formulated in the dissertation. In summary, they can be listed as:

1. A generalized classification of exact numerical and heuristic algorithms for ANN training of the multilayer perceptron type is proposed.
2. A method for training of ANN with realization of recursive descent on nodes of the tree structure of populations of the genetic algorithm with a defined selection operator in combination with local search of the best individuals has been developed.
3. The apparatus of ANN for approximation of financial time series is applied, as a result of which an approach for forecasting future values by optimizing coefficients of sinusoidal and linear equations with evolution of differences and swarms of particles (incremental optimization) is developed.
4. A heuristic approach has been developed to substitute a derivative of an activation function during ANN training.
5. A model has been developed for the implementation of ANN training in a distributed computing environment with genetic algorithms.
6. A software architecture has been developed for the implementation of the hybrid algorithms proposed in the dissertation, which has been implemented programmatically in a mobile application.

5. Abstract

The presented two versions of the abstract in Bulgarian and English reliably reflect the content of the dissertation and meet the requirements of the Law on the Development of the Academic Staff in the Republic of Bulgaria.

6. Assessment of compliance with the minimum national requirements

The doctoral student Petar Tomov has tested parts of his dissertation in eleven scientific publications, nine of them are in English and two are in Bulgarian. Two of the publications are indexed in Scopus, one of them is in an edition with SJR = 0.249. Other publications are in peer-reviewed journals or in edited collective volumes.

According to the minimum national requirements for obtaining the "Doctor" in the professional field 5.3 Communication and Computer Engineering defined in the Law on the Development of the Academic Staff in the Republic of Bulgaria requires at least 30 points on the Group of indicators G. The same number of points is required by the Regulations on the terms and conditions for acquiring scientific degrees and for holding academic positions at BAS and of the Regulations on the specific conditions for acquiring scientific degrees and for holding academic positions at IICT-

BAS. The presented publications on the dissertation form a total sum of points for the indicators from Group G equal to 109 points, which significantly exceeds the required minimum of 30 points.

Attached is a list of citations, which shows that four of the candidate's works have been cited in 12 scientific publications. This proves the necessary publicity of the results achieved in the scientific community.

Good mastery of a wide range of software tools was reflected in receiving the prestigious Award in the competition for global scalable optimization during the International Conference on High Performance Computing in 2019.

7. Notes and recommendations

The dissertation makes a very good impression with the scope, depth and argumentation of the exhibition. The field of time series forecasting is complex and achieving significant results in it requires an interdisciplinary approach. The achieved results are original and correspond to the set topic.

As critical remarks, I would like to mention a few of an editorial and technical nature, such as: Figures 2.1-2.9 are difficult to read and could be presented in a more convenient way for the comparative evaluation of the performed calculations. The list of bibliographic sources contains mainly classical works and could be updated with more recent research in the field. It would be good to move the more conceptual part of the fourth chapter in an appropriate way to the overview chapter and to show clearly the relationship between the methods, algorithms and approaches developed in the second chapter.

These notes are not the essence of the work and do not reduce the value of contributions to the dissertation.

8. Final complex assessment

I believe that the presented dissertation meets the requirements of the Law on the Development of Academic Staff in the Republic of Bulgaria. The achieved results give me reason to give a positive assessment and I recommend to the esteemed Scientific Jury to award the educational and scientific degree "Doctor" to Petar Rosenov Tomov in professional field 5.3 Communication and Computer Engineering, PhD program "Communication Networks and Systems".

15.06.2022 г.
Sofia

На основание
ЗЗЛД