BUCHAREST UNIVERSITY OF ECONOMICS STUDIES
Doctoral School of Economic Informatics

DOCTORAL THESIS

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Thesis title:
ANALYZING AND PREDICTING ECONOMIC DATA USING DEEP LEARNING TECHNIQUES

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CONTENT

SUMMARY

The main goal of the PhD thesis is to develop methodologies based on Deep Learning (DL) techniques for analyzing and predicting economic data. The data to be analyzed are generally modeled by time series.

The first type of data is stock market indices. They are essential tools in assessing the performance of a stock market or a specific segment of it. Stock market indices are important because they provide investors with a benchmark for overall market performance and allow benchmarking the performance of investment funds and other portfolios.

The second category of data studied is exchange rates. These are defined as the rate at which one currency can be exchanged for another currency and are used all over the world, both at the level of the general economy and at the level of the individual. It is thus a global indicator. Naturally, exchange rates influence the prices of goods and services, thereby affecting international trade, capital flows and investment.

A relatively new category of financial data is cryptocurrencies. These are digital (virtual) currencies that use cryptography for security. Cryptocurrencies are highly volatile, with prices that can fluctuate dramatically in a short timeframe, which can be attributed to speculation, variable regulation and market perceptions. Obviously, high volatility can offer opportunities for quick gains, but it also carries significant risks for investors.

STRUCTURE OF THE PAPER

The paper is structured in two main parts. These are represented by the review of the theoretical literature in the field and the practical methods developed, respectively. The organization is in chapters as follows.

Part I. CURRENT STATE OF KNOWLEDGE IN THE FIELD

The first part of the thesis comprises, in addition to the introduction, two chapters, in which studies on the main research directions and classical methodologies are presented, based on the literature relevant to the field.

Chapter 2: This chapter presents theoretical elements about variable selection methods, feature extraction, data filtering techniques and technical indicators specific to time series analysis. The main feature extractors are mentioned: principal and principal component analysis, independent component analysis and frequency-domain and joint time-frequency domain representations, respectively. Also, a variant of the weighted moving average is proposed, an

indicator used in the preprocessing of time series for the practical study presented in the following chapters. This indicator variant is based on the exponential rank probability distribution.

Chapter 3: Prediction methods. The third chapter aims at presenting the NAR and NARX mathematical models, statistical prediction methods, as well as recent ML and DL techniques. The main metrics for evaluating the quality of the proposed models are also presented. The last part of the chapter introduces concepts about evolutionary optimizations that can be attached to classical prediction models, such as genetic algorithms, swarm intelligence algorithms and evolutionary strategies.

Part II. PERSONAL CONTRIBUTIONS, RESEARCH METHODOLOGY AND EXPERIMENTAL RESULTS

The second part of the paper consists of three chapters and a conclusion section. This is dedicated to personal contributions and contains the proposed models and algorithms, highlighting the innovations in the field under study.

Chapter 4: DEVELOPMENT OF A HYBRID PREDICTION SYSTEM BASED ON NARX MODEL AND SVM TECHNIQUE FOR THE PREDICTION OF STOCK EXCHANGE INDEXES. This chapter proposes a methodology for technical indicator selection and stock index prediction using a multi-stage hybrid model. The methodology is based on SVM techniques, spectral analysis and selection methods.

Chapter 5: NEW NEURONAL APPROACHES OF NARX-BASED PROGNOSIS MODEL. ANALYSIS AND PREDICTION OF CHANGE CURVES. The chapter proposes three methodologies using NARX method, one methodology using LSTM in the implementation of NARX prediction model and one method using convolutional neural networks (CNNs) in the implementation of NARX prediction model.

Chapter 6: EVOLUTIONARY METHODS FOR SETTING LSTM PARAMETERS FOR TIME SERIES PREDICTION. EVOLUTION ANALYSIS OF THE EVOLUTION OF MAJOR CRYPTOCURRENCIES. An innovative evolutionary deep learning technique for analyzing and forecasting financial time series is proposed.

Chapter 7: The final chapter summarizes the whole flow of the work, the models used and the results obtained, describing some possible directions for further development of the field.

MAIN CONTRIBUTIONS

The main original contributions proposed in this paper are as follows:

- A methodology for technical indicator selection and stock index prediction using a four-stage hybrid model. The first stage is to calculate and select technical indicators based on historical stock market price data. In the next step, the lag variable is calculated. The third stage involves the use of spectral analysis tools to remove the noise contained in the data. The wavelet representation and the Gaussian low-pass filter, derived based on the Fourier transform, were used to remove the noise. The actual prediction stage uses the nonlinear SVM technique.

- Prediction methodologies developed based on NARX neural networks. The goal of these approaches is to predict the USD-RON exchange rate based on the CHF-RON exchange rate.
  - The first methodology uses the standard NARX method to which we add an additional testing step for network validation.
  - The second proposed approach is an improved variant of the first by including an additional optimization step. It retains the configuration of the NARX network for the cases where it returns satisfactory results in the training step but poor results in the testing step, and re-trains it to improve generalization capabilities.
  - The third methodology comes as a complement to the first two and is an extension of the above variant and brings new functionality that allows parameter changes for already preserved NARX network configurations.

- The following methods developed were based on three main objectives: to review LSTM-type networks by applying them on the NAR and NARX prediction model, to study convolutional networks and to analyze the performance of LSTM and CNN approaches. The main goal was the prediction of the USD-RON exchange rate. The proposed approaches include:
  - A method utilizing LSTM in the implementation of the NARX prediction model, a viable and more performing alternative compared to the standard NARX neural networks.

- A method using convolutional neural networks (CNNs) in the implementation of NARX prediction model, also a more accurate prediction alternative compared to NARX neural networks.

The conclusion of the study is that better and more stable results are obtained than the LSTM on the quantitative metrics. For the qualitative metric POCID, which reflects the trend, the results are similar but more stable for LSTM. The main purpose was the prediction of the USD-RON exchange rate.

- An improved version of the FA algorithm (Firefly Algorithm), by defining new rules for updating and handling solution space abandonment situations.
- An algorithm based on which the training of deep neural networks (Deep Learning) of the LSTM type is realized, which are configured using methods specific to evolutionary strategies. The proposed approach combines a two-member ES local search procedure with an ADAM optimizer for training LSTM neural networks to implement the NARX model. The main objective is to improve the F1-score predictions without significantly increasing the value of the MAPE error metric. The main goal of these methods is the prediction of the exchange rates of the main cryptocurrencies (BTC and ETH) and USD and the USD-EURO exchange rate. The starting point of the studies carried out was the significant volatility of cryptocurrencies compared to the main currencies and the need to obtain regressors with higher generalization power than the classical ones. The main accuracy index sought was that of evolutionary trends (correct prediction of a price increase/decrease).

POTENTIAL APPLICATIONS

There are essentially two directions in which the themes treated in this thesis have applicability to the real financial sphere. The first concerns the analysis of economic data, the main components of which are mentioned below.

Understanding market behavior: the analysis of historical data makes it possible to identify and quantify the risks associated with investments. Past volatility, for example, is a key measure derived from past price movements and is used to assess the risk of an asset.

Risk identification and mitigation: traders use past price movements to create models and algorithms that exploit market inefficiencies. Back-testing these strategies against historical data helps to assess their viability and profitability before applying them in real trades.

Regulatory and compliance analysis: For regulators and financial institutions, historical data analysis is used to ensure compliance with financial regulations and standards. This data provides a detailed record of market transactions and activities, which can be audited and reviewed to detect possible irregularities or fraudulent activity.

Enhancing financial education: historical data is a tool also applied for educational purposes. Students and professionals in finance and economics use historical market data to learn about market mechanisms, asset valuation, risk management and the impact of economic events.

Evaluating portfolio performance: investors and fund managers use historical data to compare the performance of their investments or portfolios with market indices and other benchmarks. This comparison helps to assess the effectiveness of investment strategies and to make necessary adjustments. Past performance analysis also provides a basis for setting targets and expectations for future performance.

The second main direction concerns data prediction. The main real scenarios where this information can be used are described below:

Equity portfolio management: investors use forecasts to make informed decisions on asset allocation, diversification and portfolio rebalancing. Accurate forecasts can help maximize returns and minimize risk by identifying stocks, currencies or cryptocurrencies that should be bought or sold.

Monetary policy: central banks use exchange rates and economic forecasts to decide on monetary policy (e.g. setting interest rates). Forecasting inflationary trends and economic growth help in policy decisions to stabilize the economy.

Strategic planning: corporations use market forecasts to make long-term strategic decisions, such as entering new markets, investing in new projects or planning bond issues. Accurate forecasts of economic conditions have a positive impact on future profits.

Supply chain management: businesses use forecasts to anticipate changes in exchange rates, which can influence the cost of imported goods and raw materials. This makes it easier to optimize procurement strategies and manage relationships with suppliers.

FUTURE RESEARCH DIRECTIONS

A first idea is that the proposed methodologies will be further developed by integrating more and more hybrid models that combine elements of different technical methodologies and that could lead to improvements in prediction performance. For example, the combination of traditional machine learning models with deep learning architectures or evolutionary algorithms could potentially enhance the ability to capture both linear and non-linear patterns in financial data.

Another potential direction to consider for further research is the use of the proposed models in a system where data streams are received in real time, basically real-time learning or with a limited delay. Real financial markets are dynamic and constantly evolving, and models that can adapt to new data in real time will be able to add value.

In addition, expanding the application capabilities of feature selection and processing methods can further improve model performance. The use of advanced natural language processing (NLP) techniques and a broader process of variable selection from a much larger set of potential data sources, without greatly delaying the prediction process, could represent an optimization of the current state of the art in the field.