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COMPLEX NETWORKS WITH APPLICABILITY IN FINANCIAL AND ECONOMIC ANALYSIS

PhD thesis - Abstract

to obtain the scientific Ph. D. title at
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This thesis falls within the current trends of research in the field of Computers and Information Technology, the sub-domain of complex networks, a critical and comparative analysis being determined and developed based on the obtained results.

The thesis consists of eight chapters, starting from an introductory part, containing general information, motivation and proposed and developed objectives, but also a synthesis related to the current state-of-the art in the complex network field.

The research continues across the other chapters with determination and application of methodologies and a new metric.

The final part of the paper is dedicated to conclusions, contributions, new research directions and the way the results were disseminated.

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The bibliographic references, presented after the conclusions of the eight chapters, contain 155 publications listed and described throughout the research.

The first chapter of the thesis, named *Introduction*, presents a first subchapter, which contains an overview of the use of complex networks, based on some general aspects. Thus, the research begins with the concept of algorithm, as a primary notion, but it continues with the appearance of graph theory and afterwards with the appearance of networks.

The second subchapter of the *Introduction* develops the reasons behind the choice of the research topic and the purpose of this research.

This is based on the increased interest in complex networking and the existence of a vaste amount of specialized literature in areas such as computer science and economy. Another reason for using complex networks is linked to the large amount of data that can be processed at a time. All approaches in the research are based on real statistics.

The exposed reasons lead to an increase of the scientific level in the field, based on advanced university studies and, at the same time, on formulation and solving of certain problems existing in the field of Computers and information technology, using scientific procedures.

The first chapter is continued with a subchapter covering the general and specific objectives pursued in the thesis.

Thus, the general objectives include the determination and development of some methods, techniques and algorithms that allow the analysis of certain real systems by using complex networks as well as the implementation of complex network properties on the economic and financial domains.

However, the specific objectives define the whole set of relationships and particularities in the thesis and four case studies established by identifying the data necessary for the processing.

There are certain links between complex networking and macroeconomic systems, and new correlations are obtained between the different types of data and their representation in the multidimensional space.

Another objective is connected to the complex network community concept that applies to networks that make economic exchanges. Three methods / algorithms are established and implemented to allow the interconnection between graph theory and econometrics.

Another objective is to define and define a new metric of centrality, called *CORREAL*. This metric applies to data that represents some activity sectors of the GDP macroeconomic indicator, to carefully selected financial markets, but also to some EU-28 import operations into the EU.

The second chapter, called *Current status of research in the thesis field*, refers to the current state of research in the thesis field and some defining elements are introduced, beginning with notions developing the theory of graphs, algorithms, networks, including complex networks, for a better understanding of how complex networks are used.

Following the thread of history, in 1735 Leonhard Euler studied networks, solving a first network problem, namely the problem of the seven Königsberg bridges, being considered one of the problems underlying the theory of graphs. Next, the presentation of the data transmission and network management is continued, as well as the fact that complex networks are one of the key points in the technology that is so developed today and in which the novelties appear with great rapidity. Complex networks and graph theory themselves allow, under more efficient conditions, to obtain higher value analyzes, to which classical methods fail to cope.

Also in this chapter two is offered a certain classification of complex networks, taking into account certain topologies. Identifying the structure of a community is an actual and complex area of research, and the use of network techniques helps the evolution of the domain, the most important being the determination of the most influential nodes.

At the same time, definitions are formulated and fundamental notions used in the research are introduced, being necessary for a better understanding of how the technologies used in complex networks are associated with the economic and financial environment.

Highlighting mathematical fundamentals, properties, networking techniques, existing patterns and algorithms for detection of existing communities allow the concepts and methodologies determined in the research to be accessible.

An analysis of this second chapter is also made on some categories of community detection algorithms starting with some of the classic algorithms, continuing with those using overlapping, then with a series of those based on modularity optimization, and finally with a part of those used for the detection of the communities dynamically, and there is also a schematic presentation of the highlighted algorithms, but there is also a comparative study on some modularity optimization algorithms.

Due to the applicability of complex research networks on economic and financial data, some information is also presented from an economic perspective.

The final subchapter in the second chapter refers to a synthesis based on the bibliography.

The third chapter investigates the behavior of phenomena, characterized in the form of time series. The use of complex networks allows to determine the correlations existing between certain financial data and the analysis of the obtained results, referring to Romania's gross domestic product over a longer period, covering the period 2001-2013, thus shaping 14 sectors of activity for a period of time 12 years.

Specific measurements are made and a knot grouping coefficient is used that can be used as a score in describing the country's GDP structure, being useful in comparing two or more savings.

Another aspect of this direction is related to the determination of some communities, using a detection algorithm on a filtered graph.

This highlights a new possibility of viewing data by some methods to provide experts with alternative solutions to present and interpret data. Chart-based representation and visualization provides a powerful visual way that shows the relationship between all of these data.

The novelty of the approach lies in the development of an algorithm, called the *PIBGRA* methodology, which allows the breakdown of the main sectors of the economy seen through the gross domestic product and the construction of some representations in the multidimensional space of the relations between them.

The algorithm highlights certain communities in the form of complete graphs and relevant diagrams and graphs, the data used in the algorithm being selected from the database belonging to the National Institute of Statistics of Romania.

Part of this study was exposed in the paper titled "A spatial approach in analyzing the structure and dynamics of the Romanian GDP" and presented at SACI 2014 [13].

In the fourth chapter, entitled *Methodology and results on the second research direction - complex networks with applicability in the analysis of the structure of the financial markets*, we used the complex networks that allow the processing of data regarding the dynamics of the financial markets.

The use of raw data sets and the construction of associated networks allows a further, specific analysis to be carried out by new pertinent views.

In the first instance, reference is made to data sets taken from the Eurostat database of the European Commission and focused on the exchange rates of 23 major currencies against the US dollar. The data collection is covering the period from 1 January 2000 to 1 August 2014, with a resolution per day. There are 3646 dates for each of the 23 currencies. This study is about a dual approach: there is the classic one, the temporal evolution of data and its visualization through a correlation diagram, and the other, based on the analysis of complex networks, will show us the distribution in a n-dimensional data space with emphasis on groups of strongly correlated sets.

In the second phase of the study direction, related to the structure of the global financial markets, the focus is on data sets taken from the National Bank of Romania. This time reference is made on the exchange rates of 31 major currencies, but the information is selected to be closer to the current period, including the 2005-2007 pre-crisis period but also the period that marked the crisis and continued the processing over a period for 11 years.

The development processes and the creation of models as relationships between entities is considered to be necessary, as well as constructing some spatial representations of them that allow the intuitive analysis of relations and the quantitative characterization of phenomena, given the modern economies that have to take into account many parameters, being extremely dynamic systems but with an unstable balance.

The research is focused on using complex network analysis. After defining the mechanism for building correlation networks, complete associated graphs and corresponding sub-graphs (by imposing different thresholds for correlation indices) are built.

After a 0.3 threshold is applied to the data, it is observed a statistical correlation between most major currencies of the world, regardless of the country or continent of origin.

This study also covers the design and application of the algorithm, called *CORGRA*, using techniques that involve complex networks which allow the analysis of the structure of global financial markets. The methods are applied to sets of data used globally over a period of 14 years, and some of the studies of this chapter are supported in the works and publications of [8], [13].

The third study of the thesis, built and developed in the fifth chapter, called *Methodology and results on the third research direction - complex networks for EU-28 import-export operations*, aimed the development of the *IMEXGRA* algorithm that involves the determination and application techniques of complex networks on some values of time series resulting from import-export trade operations between EU-28 countries and looked at certain time periods since 2007, i.e. from the time of our country's integration into the European Union.

Intervention in the thesis is a dynamic one, including a long period of data analysis, or a brief period under analysis, allowing analysts new perspectives of approaching the interpretation of data over short or long periods of time. If we focus on the same communities in two consecutive years, we can see that the modularity factor is almost doubled. The Pearson Correlation Index and the 0.3 index threshold is applied to different communities allow the observation of differences generated over time, both in terms of imports and exports in the EU-28.

The novelty of the approach lies in the use of complex networks implemented through targeted graphs, allowing safe and efficient comparison of two or more economies.

Part of the studies of this chapter were exposed in the research paper "Complex networks analysis of international import-export trade".

The sixth chapter was intended for creative thinking elements and targeted the stock market, involving top industry indices. This chapter of research has combined, through complex networks, financial elements that can influence existing economic relations at the current level among the world's countries. This time, in the thesis, the selected sets were derivatives of the capital markets, namely certain stock indices retained for processing.

Part of the studies of this chapter were published in the paper "Complex Networks with the Applicability to the Structure and Dynamics of Stock Market Evolution".

In the seventh chapter, called *Economic networks*, a new metric of centrality, *CORREAL*, was proposed, which was defined and then applied on data from the first three case studies of the research.

In the first situation, with reference to GDP in Romania, the *CORREAL* metric has been applied to the 14 network nodes that are key sectors selected and processed throughout the

research, and whose graphical representation has allowed the highlighting of certain nodes in the network.

The second graphical representation of *CORREAL*'s core metric has provided the opportunity to perform a pertinent analysis of 23 time series, representing for about 14 years the exchange rate of the US dollar.

A new graphical representation was applied to data from the third case study. This time, reporting was made based on time-series, being exposed to the analysis the 2007 data, by applying the *CORREAL* metric, with reference to EU import-led 28.

At the same time, a series of data measurements were applied on the first three directions by using different coefficients of indexing, obtaining series of values found in the thesis, the data allowing a study to be obtained in comparison to the *CORREAL* metric on each selected sub-field.

In the eighth chapter, a synthesis of the research work is made as well as the personal contributions proven by the articles presented and published in international conferences and the publications in the journals found in the sub-chapter 8.4.

One of the contributions is to add new methods for describing the importance of a network (economic system) within a global topology based on the *betweenees* metric. Another contribution is the identification of hidden correlations in the field of commodity and currencies exchange networks through the methods and metrics specific to complex network theory and the creation of a new *CORREAL* central metric. A new contribution is related to community detection using network topology by scaling the resolution with a 0.1 step in order to determine the inflection point of the graph that includes the number of communities and the resolution. The realization of three algorithms / methodologies of representation in a multidimensional space of the information specific to the economic domain and of a comparative schematic study to extract low-dimensional information from the upper data sets is a new contribution, as well as the realization of four case studies with demonstrative applications to highlight the usefulness of those introduced through the analysis of economic interactions at the level of gross domestic product, the structure of financial markets, commodity exchange on import and export, and the stock market.

Also this chapter specifies eight new proposals for future research.

Both statistical calculations and plotting of the graphs presented were made using the R programming language, version 3.0.2 and were executed on Windows 7 Ultimate Edition, the x64 platform. We are dealing with graphical representations and visualizations, all of which are made using Gephi 0.8, or 0.9.1 one of the most important OpenSource network analysis tools.

At the end of the research were exposed some annexes of research containing part of the data sets on which the measurements were made.

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