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Janusz Kacprzyk, Polish Academy of Sciences, Warsaw, Poland
e-mail: kacprzyk@ibspan.waw.pl

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Mikhail Z. Zgurovsky · Yuriy P. Zaychenko

The Fundamentals of Computational Intelligence: System Approach

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Mikhail Z. Zgurovsky
National Technical University of Ukraine
Kiev
Ukraine

Yuriy P. Zaychenko
Institute for Applied System Analysis
National Technical University of Ukraine
"Kiev Polytechnic Institute"
Kiev
Ukraine

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Preface

The intention of mankind to reveal the essence of brain intelligence and utilize it in computers arose already at the initial stage of cybernetics. These aspirations led to the appearance of new scientific field—artificial intelligence (AI) in the middle of the twentieth century. The main goal of new science became the detection of brain work mechanism and development on this base artificial systems for creative processes automation in information processing and decision-making.

In the past 60 years artificial intelligence has passed complex way of its evolutionary development. On this way were both significant achievements and failures. During the first 40 years of its development in AI several scientific branches were formed such as knowledge bases, expert systems, pattern recognition, neural networks, fuzzy logic systems, learning and self-learning, self-organization, robotics, etc.

In the 1990s by integrating various AI technologies and methods new scientific branch in AI was formed which was called "computational intelligence." This branch appeared as a consequence of practical problems which could not be solved using conventional approaches and methods. In particular these problems have occured while solving the problems of data mining, problems of decision-making under uncertainty, so-called ill-structured problems for which the crisp problem statement was impossible.

The suggested monograph is dedicated to systematic presentation of main trends, approaches, and technologies of computational intelligence (CI). The introduction includes brief review of CI history, the authors' interpretation of CI, the analysis of main CI components: technologies, models, methods, and applications. The interconnections among these components are considered and relations between CI and soft computing are indicated.

Significant attention in the book is paid to analysis of the first CI technology—neural networks. The classical neural network backpropagation (NN BP) is described, the main training algorithms are considered. The important class of neural networks—with radial basic functions is described and its properties are compared with NNBP. The class of neural networks with backfeed—Hopfield and

Hamming are described and their properties and methods of weights adjustment are considered. The results of experimental investigations of these networks in the problem of images recognition under high level of noise are presented and compared. NN with self-organization by Kohonen are considered, its architecture and properties are described and various algorithms of self-organization are analyzed. The application of Kohonen neural networks in the problems of automatic classification and multidimensional visualization is considered.

Great attention in monograph is paid to novel important CI technology—fuzzy logic (FL) systems and fuzzy neural networks (FNN). The general description of fuzzy logic systems is provided, main stages of fuzzy inference process and fuzzy logic algorithms are described. The comparative analysis of fuzzy logic systems properties is presented, their advantages and drawbacks are analyzed. On this base the integration of two CI technologies—NN and FL was performed and as a result the new CI technology was created—fuzzy neural networks. Different FNN are described and their training algorithms are considered and compared.

New class of FNN—cascade neo-fuzzy neural networks (CNFNN) are considered, its architecture, properties, and training algorithms are analyzed. The applications of FNN to the forecast in economy and at stock markets are presented. The most efficient algorithms of fuzzy inference for the problem of forecasting in economy and financial sphere are determined.

The problem of investment portfolio optimization under uncertainty is considered. The classical portfolio optimization problem by Markovitz is described, its advantages and drawbacks are analyzed. The new problem statement of portfolio optimization under uncertainty is considered, which is free of drawbacks of classical model. The novel theory of fuzzy portfolio optimization is presented. For its solution corresponding method based on fuzzy sets approach is suggested. The application of the elaborated theory for investment portfolios determination at Ukrainian, Russian, and American stock exchanges is presented and analyzed.

The problem of corporations bankruptcy risk forecasting under incomplete and fuzzy information is considered. The classical method by Altman is described and analyzed. New methods based on fuzzy sets theory and fuzzy neural networks are suggested. Results of fuzzy methods application for corporations bankruptcy risk forecasting are presented, analyzed, compared with Altman method and the most adequate method was determined.

This approach was extended to the problem of banks bankruptcy risk forecasting under uncertainty. The experimental results of financial state analysis and bankruptcy risk forecasting of Ukrainian and leading European banks with application of fuzzy neural networks ANFIS, TSK, and fuzzy GMDH are presented and analyzed.

The actual problem of creditability analysis of physical persons and corporations is considered. The classical scoring method of creditability analysis is described and its drawbacks are detected. New method of corporations creditability estimation under uncertainty is suggested based on application of FNN. The comparative investigations of corporations creditability forecasting using classical scoring method and FNN are presented and discussed.

The application fuzzy neural networks in the problem of pattern recognition is considered. The applications of FNN for pattern recognition of optical images, handwritten text, are considered.

Great attention in monograph is paid to inductive modeling method, so-called group method of data handling (GMDH). Its main advantage lies therein it enables to construct the structure of forecasting model automatically without participation of an expert. By this possibility GMDH differs from other identification methods. The new fuzzy GMDH method suggested by authors is described which may work under fuzzy and incomplete information. The problem of inductive models adaptation obtained by FGMDH is considered. The results of numerous experimental investigations of GMDH for forecasting at stock exchanges in Ukraine, Russia, and USA are presented and analyzed.

The problems of cluster analysis and automatic classification are considered in detail. The classical and new methods of cluster analysis based on fuzzy sets and FNN are described and compared. The applications of cluster methods for automatic classification of UNO countries by indices of sustainable development are presented and analyzed.

The final chapters are devoted to theory and applications of evolutionary modeling (EM) and genetic algorithms (GA). The general schema and main mechanisms of GA are considered, their properties and advantages are outlined. Special section is devoted to new extended GA. The applications of GA for computer networks structure optimization are considered.

Basic concept and main trends in evolutionary modeling are considered. The evolutionary strategies for artificial intelligence problems solution are presented and discussed. Special attention is paid to the problem of accelerating the convergence of genetic and evolutionary algorithms.

In the conclusion the perspectives of computer intelligence technologies and methods development and implementation are outlined.

The distinguishing features of this monograph are a great number of practical examples of CI technologies and methods and applications for solution of real problems in economy and financial sphere, in particular forecasting, classification, pattern recognition, portfolio optimization, bankruptcy risk prediction of corporations and banks under uncertainty which were developed by the authors and are published in the book for the first time. Just system analysis of presented experimental and practical results enables to estimate the efficiency of the presented methods and technologies of computational intelligence.

All CI methods and algorithms are considered from the general system approach and the system analysis of their properties, advantages, and drawbacks is performed that enables practicians to choose the most adequate method for their own problems solution.

The proposed monograph is oriented first of all to the persons who aspire to make acquaintance with possibilities of current computer intelligence technologies and methods and to implement them in practice. It may also serve as inquiry book on contemporary technologies and methods of CI, it will be useful for students of corresponding specialties.

Contents

Introduction

Human desire to improve the efficiency of own decisions constantly stimulated the development of appropriate computational tools and methods. These tools are characterized by increasing automation and intellectualization of their creative operations, which were previously considered to be the prerogative exclusively of human being with the advent of the computer the question had arisen: Can a machine “think”, is it possible to transfer to a computer a part of human intellectual work? To this sphere refer modeling of certain functions of the human brain, in particular, pattern recognition, fuzzy logic, self-learning, and other creative human activities.

History of work in the field of artificial intelligence counts more than 50 years. The term artificial intelligence (AI) first appeared in 1956, when at Dartmouth College USA the symposium entitled “Artificial Intelligence” (AI) was held, dedicated to solving logic rather than computational problems using computers. This date is the moment of the birth of a new science. Over the years, this branch of science had passed a difficult and instructive way of development. It has formed a number of such fields, as systems based on knowledge, the logical inference, the search for solutions, the pattern recognition systems, machine translation, machine learning, action planning, agents and multi-agent systems, self-organization and self-organizing systems, neural networks, fuzzy logic and fuzzy neural networks, modeling of emotions and psyche, intellectual games, robots and robotic systems, and others.

Currently, there are many definitions of the term Artificial Intelligence. It makes no sense to bring them all in this book. In our view, more important is to highlight the main features and properties that distinguish AI from conventional automation systems for certain technologies. These properties include:

1. the presence of the goal or group of goals of functioning, the ability to set goals;
2. the ability to plan their actions to achieve the goals, finding solutions to problems that arise;
3. the ability to learn and adapt their behavior in the course of work;
4. the ability to work in poorly formalized environment in the face of uncertainty;

5. work with fuzzy instructions;
6. the ability to self-organization and self-development;
7. the ability to understand natural language texts;
8. the ability to generalization and abstraction of accumulated information.

In order to create a machine that would approach in its capabilities to the properties of the human brain, it is necessary, first of all, to understand the nature of human intelligence, to reveal the mechanisms of human thinking. Over the past decade, this issue was the subject of many works. Among the works that have appeared in recent years, it is necessary to appreciate the monograph by Jeff Hawkins and Sandra Blakeslee "On intelligence," translated from English.—M.: Ltd. "P.H. Williams," 2007, in which the authors, in our opinion, had come closest to the understanding the basis of human intelligence. In it the authors, at the intersection of neuroscience, psychology and cybernetics have developed a pioneering theory in which a model of the human brain, was constructed. The main functions of developed model are remembering past experiences and predicting by the brain results of the perception of reality and its own actions. The authors presented many convincing examples of human behavior in different circumstances, which support this idea. So, Jeff Hawkins writes: "… Forecasting, in my opinion, is not just one of the functions of the cerebral cortex, it is the primary function of the neocortex, and the base of intelligence. The cerebral cortex is the organ of vision. If we want to understand what is the intellect, what is creativity, how our brain works, and how to build intelligent machines, we need to understand the nature of forecasts and how the cortex builds them."

Since many years of research work in the field of AI in the early 1990s by integrating a number of intelligent technologies and methods a new direction in the field of AI, called computational intelligence (CI) was created.

There are several definitions of the term computational intelligence. For the first time the term "computational intelligence" (CI) was introduced by Bezdek [1] (1992, 1994), who defined it as: "a system is intelligent in computational sense, if it: operates only with digital data; has a recognition component; does not use knowledge in the sense of artificial intelligence and in addition, when it exhibits:

(a) computing adaptability;
(b) computing fault tolerance;
(c) the error rate that approximates human performance."

Afterward, this definition was clarified and expanded. Marx in 1993 in defining CI focused on technology components of CI [2]: "… neural networks, genetic algorithms, fuzzy systems, evolutionary programming and artificial life are the building blocks of CI."

Another attempt of CI definition was made by Vogel [3]: the technologies of neural networks, fuzzy and evolutionary systems have been integrated under the guise of "computational intelligence"—a relatively new term suggested for the general description of the computational methods that can be used to adapt to new problems solutions and are not based on explicit human knowledge.

Over the years, a large number of works has appeared devoted to various areas in the field of CI, regularly many international conferences and congresses on Computational Intelligence are held, IEEE International Institute publishes a special magazine devoted to the problems of computational intelligence—IEEE Transactions on Computational Intelligence.

The analysis of these works allows us to give the following definition of CI [4].

Under computational intelligence (*CI*) *we'll understand the set of methods, models, technologies and software designed to deal with informal and creative problems in various spheres of human activity, using the apparatus of logic, which identify to some extent mental activity of human, namely, fuzzy reasoning, qualitative and intuitive approach, creativity, fuzzy logic, self-learning, classification, pattern recognition and others.*

It is worth noting the relationship between artificial intelligence (AI) and computational intelligence. CI is an integral part of modern AI using special models, methods, and technologies and focused on solving certain classes of problems.

The structure of CI areas and methods is shown in Fig. 1.

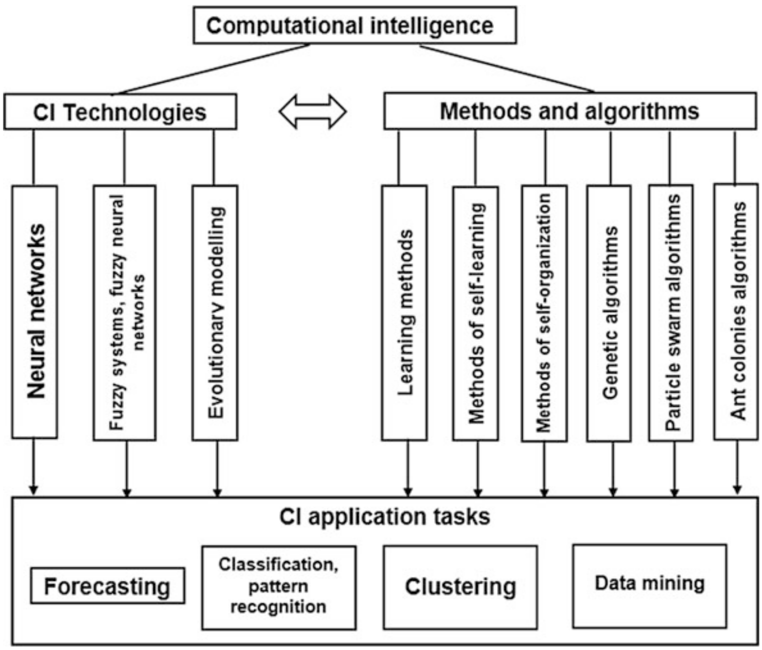

Fig. 1 Structure of computational intelligence

The structure CI includes the following components [4]:

- Technologies;
- Models, methods, and algorithms;
- Applied tasks.

CI Technologies include:

- Neural networks (NN);
- Fuzzy logic systems (FLS) and fuzzy neural networks (FNN);
- Evolutionary modeling (EM).

CI methods and algorithms include:

- Learning methods;
- Methods of self-learning;
- The methods of self-organization;
- Genetic algorithms (GA);
- Particle swarm algorithms;
- Ant colonies algorithms.

CI technologies and techniques are used for solution of relevant applied problems of AI. It is reasonable to distinguish the following basic classes of CI applied problems inherent of human mental activity:

- Forecasting and foresight;
- Classification and pattern recognition;
- Clustering, spontaneous decomposition of the set of objects into classes of similar objects;
- Data Mining;
- Decision-Making.

The term CI is close in meaning, which is widely used in foreign literature the term "soft computing" [5], which is defined as a set of models, methods, and algorithms based on the application of fuzzy mathematics (fuzzy sets and fuzzy logic).

The concept of soft computing was first mentioned in the work of L. Zadeh to analyze soft (soft) data in 1981. Soft computing (SC)—a sophisticated computer methodology based on fuzzy logic (FL), genetic computing, neurocomputing, and probabilistic calculations. Its components do not compete but create synergies. The guiding principle of soft computing is accounting errors, uncertainty, and approximation of partial truth to achieve robustness, low-cost solutions which are more relevant to reality.

Four soft computing components include:

- Fuzzy logic—approximate calculations, information granulation, the calculation in words;
- Neurocomputing—training, adaptation, classification, system modeling, and identification;
- Genetic computing—synthesis, configuration, and optimization using a systematic random search and evolution;
- Probability calculations—management of uncertainty, belief networks, chaotic systems, a prediction.

Traditional computer calculations (hard computing) is too accurate for the real world. There are two classes of problems for soft computing. First, there are problems, for which complete and accurate information is not available and cannot be obtained, and, second, the problems whose definition is not sufficiently complete (uncertain).

Thus, between the computational intelligence (CI) and soft computing are much in common: common paradigms, principles, methods, technologies, and applied problems. Differences between them, in our opinion, consist of approach, SC focuses on methodological, philosophical, and mathematical problems, while CI focuses mainly on the computer algorithms, technology, and the practical implementation of the relevant models and methods.

Technologies and methods of CI are widely used for applications. Thus, neural networks (NN) and fuzzy neural networks are used to predict the nonstationary time processes, particularly in the economy and the financial sector.

NN and GMDH are widely used in problems of classification and pattern recognition problems in diagnostics, including technical and medical spheres.

Neural network self-organization, cluster analysis methods (clear and fuzzy) are used in the automatic classification of objects by their features of similarity—difference.

Evolutionary modeling, genetic algorithms are used for the synthesis of complex systems, pattern recognition, classification, and optimization of computer networks structure. In addition, genetic and particle swarms algorithms are widely used in combinatorial optimization problems, in particular for graphs optimization.

Systems with fuzzy logic and FNN are effectively used for the analysis of the financial state of corporations, prediction of corporations and banks bankruptcy risk, assessment of the borrowers creditworthiness under uncertainty.

Thus, summing up, it should be noted that modern CI technologies and methods closely interact with each other. There is a deep interpenetration of methods and algorithms of computational intelligence into the appropriate technology, and vice versa.

Further development of computational intelligence apparently will go in several directions.

First—it is the extension of CI applications problems, new applications in different tasks and subject areas, such as economy, finance, banking, telecommunication systems, process control, etc.

Second, it is the development and improvement of CI methods themselves, in particular, genetic (GA) and evolutionary algorithms (EA), swarm optimization algorithms, immune algorithms, ant algorithms. One promising area is the adaptation of learning parameters of genetic and evolutionary algorithms in order to accelerate convergence and improve the accuracy of solutions in optimization problems. Relevant is the development and improvement of parallel genetic algorithms.

Third, it is the further integration of various CI technologies, for example, the integration of fuzzy logic and genetic and evolutionary algorithms in problems of decision-making and pattern recognition in conditions of incompleteness of information and uncertainty, genetic and swarm algorithms, as well as algorithms for their learning and self-learning.

The presentation of CI basic techniques and methods, as well as their application to the solution of numerous application problems in various areas: forecasting, classification, pattern recognition, cluster analysis, and risk forecasting in industrial and financial spheres constitute the main content of this monograph.