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Computational Intelligence in Time Series Forecasting

Theory and Engineering Applications

With 66 Figures

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Writing a book of this volume involves great strength, devotion and the commitment of time, which are lost for our families. We are, therefore, most grateful to our wives, Mrs. Soma Palit and Mrs. Irene Popovic, for their understanding, patience and continuous encouragement, and also to small Ananya Palit who missed her father on several weekends and holidays.

A. K. Palit and D. Popovic

Series Editors' Foreword

The series *Advances in Industrial Control* aims to report and encourage technology transfer in control engineering. The rapid development of control technology has an impact on all areas of the control discipline. New theory, new controllers, actuators, sensors, new industrial processes, computer methods, new applications, new philosophies..., new challenges. Much of this development work resides in industrial reports, feasibility study papers and the reports of advanced collaborative projects. The series offers an opportunity for researchers to present an extended exposition of such new work in all aspects of industrial control for wider and rapid dissemination.

Computational Intelligence is a newly emerging discipline that, according to the authors Ajoy Palit and Dobrivoje Popovic, is about a decade old. Obviously, this is a very young topic the definition and content of which are still undergoing development and change. Nonetheless, the authors have endeavoured to give the topic a framework and demonstrate its procedures on challenging engineering and commercial applications problems in this new *Advances in Industrial Control* monograph, *Computational Intelligence in Time Series Forecasting*.

The monograph is sensibly structured in four parts. It opens with an historical review of the development of "Soft Computing" and "Computational Intelligence". Thus, Chapter 1 gives a fascinating insight into the way a new technology evolves and is consolidated as a self-evident discipline; in this case, proposals were made for constituent methods and then revised in the light of applications experience and the development of new methodologies which were added in to the core methods. No doubt the debate will continue for a few more years before widely accepted subject definitions appear, but it is very useful to have a first version of a "Computational Intelligence" technology framework to consider.

In Part II, the core methods within Computational Intelligence are presented: neural networks, fuzzy logic and evolutionary computation – three neat self-contained presentations of the building blocks for advanced development. It is in Part III that new methods are developed and presented based on hybridisation of the three basic routines. These new hybrid algorithms are demonstrated on various application examples. For the practicing engineer, chapters in Part II and III should almost provide a self-contained course on Computational Intelligence methods.

The current and future development of Computational Intelligence methods are the subject of Chapter 10 which forms Part IV of the monograph. This chapter balances the historical perspective of Chapter 1 by attempting to identify new development areas that might be of significant interest to the engineer. This is not an easy task since even a quick look at Chapter 10 reveals an extensive literature for a rapidly expanding field.

This volume on Computational Intelligence by Dr. Palit and Dr. Popovic is a welcome addition to the *Advances in Industrial Control* monograph series. It can be used as a reference text or a course text for the subject. It has a good opening historical review and a nice closing chapter looking to the future. Most usefully, the text attempts to present these new algorithms in a systematic framework, which usually eases comprehension and will, we hope, lead the way to a new technology paradigm in industrial control methods.

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Preface

In the broad sense, computational intelligence includes a large number of intelligent computing methodologies and technologies, primarily the evolutionary, neuro and fuzzy logic computation approaches and their combinations. All of them are derived through the studies of behaviour of natural systems, particularly of the connectionist and reasoning behaviours of the human brain/human being.

The computational technology was evolved, in fact, from what was known as soft computing, as defined by Zadeh in 1994. Also, soft computing is a multidisciplinary collection of computational technologies still representing the core part of computational intelligence. The introductory chapter of this book is dedicated to the evolutionary process from soft computing to computational technology. However, we would like to underline that computational intelligence is more than the routine-like combination of various techniques in order to calculate “something”; rather, it is a goal-oriented strategy in describing and modelling of complex inference and decision-making systems. These soft computing approaches to problem formulation and problem solution admit the use of uncertainties and imprecisions. This, to a certain extent, bears a resemblance to artificial intelligence strategies, although these emphasize knowledge representation and the related reasoning rather than the use of computational components.

Computational intelligence, although being not more than one decade old, has found its way into important industrial and financial engineering applications, such as modelling, identification, optimization and forecasting required for plant automation and making business decisions. This is due to research efforts in extending the theoretical foundations of computationally intelligent technologies, exploiting their application possibilities, and the enormous expansion of their capabilities for dealing with real-life problems.

Although in the near past books on computational intelligence and soft computing have been published, today there is no other book dealing with the systematic and comprehensive expositions of methods and techniques for solving the forecasting and prediction problems of various types of time series, *e.g.* nonlinear, multivariable, seasonal, and chaotic. In writing this book our intention was to offer researchers, practising engineers and applications-oriented professionals a reference volume and a guide in design, building, and execution of

forecasting and prediction experiments, and this includes from the collection and structuring of time series data up to the evaluation of experimental results.

The fundamental knowledge and the methodologies of computationally intelligent technologies were drawn from various courses for advanced students and from the experimental studies of Ph.D. candidates at the Institute of Automation Technology of University of Bremen, the Control Engineering Laboratory of Delft University of Technology, and from our experience in co-operation with industry. The material presented in the book is therefore suitable to be used as a source in structuring the one-semester course on intelligent computational technologies and their applications.

The book is designed to be largely self-contained. The reader is supposed to be familiar with the elementary knowledge of neural networks, fuzzy logic, optimum search technique, and probability theory and statistics. The related chapters of the book are written so that the reader is systematically led to the deeper technology and methodology of the constituents involved in computational intelligence and to their applications. In addition, each chapter of the book is provided with a list of references that are intended to enable the reader to pursue individual topics in greater depth than that has been possible within the space limitations of this book. To facilitate the use of the book, an index of key terms is appended.

The entire book material consists of 10 chapters, grouped into four parts, as described in the following.

Part I of the book, containing the first two chapters, has the objectives of introducing the reader to the evolution of computational intelligence and to the traditional formulation of the time series forecasting problem and the approaches of its solution.

The evolution of computational intelligence is presented in the introductory Chapter 1, starting with the soft computing as developed by Zadeh in 1994 up to the present day. During this time, the number of constituents of computational intelligence has grown from the fuzzy logic, neurocomputing, and probabilistic reasoning as postulated by Zadeh, with the addition of genetic algorithms (GAs), genetic programming, evolutionary strategies, and evolutionary programming. Particular attention is paid to the achievements of hybrid computational intelligence, which deals with the parameter tuning of fuzzy systems using neural networks, performance optimization of neural networks through monitoring, and parameter adaptation by fuzzy logic systems, *etc.* The chapter ends with the application fields of computational intelligence today.

The ensuing Chapter 2 is devoted to the traditional definition and solving of the time series forecasting problem. In the chapter, after the presentation of the main characteristic features of time series and their classification, the objective of time series analysis in the time and frequency domains is defined. Thereafter, the problem of time series modelling is discussed, and the linear regression-based time series models that are mostly used in time series forecasting are presented, like the ARMA, ARIMA, CARIMA models, *etc.*, as well as some frequently considered models, such as the multivariate, nonlinear, and chaotic time series models. This is followed by the discussion of model estimation, validation, and diagnostic checks on which the acceptability of the developed model depends. The core part of the chapter, however, deals with the forecasting approaches of time series based on

Box-Jenkins methods and the approaches using exponential smoothing, adaptive smoothing, and the nonlinear combination of forecasts. The chapter ends with an example in control engineering from the industry.

In Part II of the book, which is made up of Chapters 3, 4, and 5, the basic intelligent computational technologies, *i.e.* the neural networks, fuzzy logic systems, and evolutionary computation, are presented.

In Chapter 3 the reader is introduced to neuro-technology by describing the architecture, operating principle, and the application suitability of the most frequently used types of neural network. Particular attention is given to various network training approaches, including the training acceleration algorithms. However, the kernel part of the chapter deals with the forecasting methodology that includes the data preparation, determination of network architecture, training strategy, training stopping and validation, *etc.* This is followed by the more advanced use of neural networks in combination with the traditional approaches and in performing the nonlinear combination of forecasts.

Chapter 4 provides the reader with the foundations of fuzzy logic methodology and its application to fuzzy modelling on examples of building the Mamdani, relational, singleton, and Takagi-Sugeno models, suitable for time series modelling and forecasting. Special attention is paid to the related issues of optimal shaping of membership functions, to automatic rules generation using the iterative clustering from time series data, and to building of a non-redundant and conflict-free rule base. The examples included deal with chaotic time series forecasting, and modelling and prediction of second-order nonlinear plant output using fuzzy logic systems. Also here, the advantage of nonlinear combination of forecasts is demonstrated on temperature prediction in a chemical reactor.

In Chapter 5 the main approaches of evolutionary computations or intelligent optimal solution search algorithms are presented: GAs, genetic programming, evolutionary strategies, evolutionary programming, and differential evolution. Particular attention is paid to the pivotal issues of GAs, such as the real-coded GAs and the optimal selection of initial population and genetic operators.

Part III of the book, made up of Chapters 6 through to 9, presents the various combinations of basic computational technologies that work in a cooperative way in implementing the hybrid computational structures that essentially extend the application capabilities of computational intelligence through augmentation of strong features of individual components and through joint contribution to the improved performance of the overall system.

The combination of neuro and fuzzy logic technology, described in Chapter 6, is the earliest experiment to generate hybrid neuro-fuzzy and fuzzy-neuro hybrid computational technology. The motivation for this technology merging, which in the mean time is used as a standard approach for building intelligent control systems, is discussed and the examples of implemented systems presented. Two major issues are pointed out: the training of typical neuro-fuzzy networks and their application to modelling nonlinear dynamic systems. In order to demonstrate the improved capability and performance of neuro-fuzzy systems, their comparisons with backpropagation and radial basis function networks are presented. Finally, forecasting examples are given from industrial practice, such as short-term forecasting of electrical load, prediction of materials properties, correction of

pyrometer readings, tool wear monitoring, as well as the examples on modelling and prediction of Wang data and on prediction of chaotic time series.

The subjects of the succeeding Chapter 7 are two most important, but very often neglected, and recently increasingly considered issues of model transparency and the interpretability of data-driven automated fuzzy models. Here, strong emphasis is placed on making the reader familiar with the compact and transparent modelling schemes that include the model structure selection, data clustering, similarity-based simplification, and model validation. In addition, the similarity-based rule base simplification through removing irrelevant fuzzy sets, removing redundant inputs, and the merging of rules are presented. In this chapter some formal techniques are proposed for regaining the interpretability and transparency of the generated fuzzy model, which helps in generating the “white-box-like” model, unlike the black-box model generated by a neural network.

Chapter 8 covers the application of GAs and evolutionary programming in evolution design of neural networks and fuzzy systems. This is a relatively new application field of evolutionary computation that has, in the past decade, been the subject of intensive research. The text of the chapter focuses on evolving the optimal application-oriented network architecture and the optimal values of their connection weights. Correspondingly, optimal selection of fuzzy rules and the optimal shaping of membership function parameters are on the agenda when evolving fuzzy logic systems.

Chapter 9, again, deals in a sense with the inverse problem, *i.e.* with the problem of adaptation of GAs using fuzzy logic systems for optimal selection and tuning of genetic operators, parameters, and fitness functions. In the chapter, the probabilistic control of GA parameters and - in order to avoid the prematurity of convergence - the adaptation of population size while executing of search process is discussed. The chapter closes with the example of dynamically controlled GA using a rule-based expert system with a fuzzy government module for tuning the GA parameters.

Part IV of the book, consisting of Chapter 10, introduces the reader to some more recently developed computationally intelligent technologies, like support vector machines, wavelet and fractal networks, and gives a brief outline about the development trends. In addition, the entropy and Kohonen networks-based fuzzy clustering approaches are presented and their relevance to the time series forecasting problem pointed out, for instance through the design of Takagi-Sugeno fuzzy model. In the introductory part of the chapter the reasons for selecting the above items of temporary computational intelligence are given. It is also indicated that the well advanced bioinformatics, swarm engineering, multi-agent systems, and fuzzy-logic-based data understanding are the constituents of future emerging intelligent technologies.

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Part I

Introduction