Computational Intelligence and Its Applications
计算智能及其应用

By
Xin Yao
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内 容 简 介

本书阐述计算智能的理论和相关的应用。重点介绍了如下三个方面的内容：计算智能的前沿技术，可以用计算智能的方法来解决的前沿问题，计算智能的最新技术在相关领域的应用。本书可作为信息科学技术领域高年级本科生和研究生的针对计算智能的入门教材，也可以供从事科研和技术开发的人员参考。IEEE 计算智能协会（www.ieee-cis.org）是该领域重要学术组织，并为本书编写提供很大帮助。

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编 委 会

总　　序

侯建国
(中国科学技术大学校长、中国科学院院士、第三世界科学院院士)

大学最重要的功能是向社会输送人才. 大学对于一个国家、民族乃至世界的重要性和贡献度, 很大程度上是通过毕业生在社会各领域所取得的成就来体现的.

中国科学技术大学建校只有短短的五十年, 之所以迅速成为享有较高国际声誉的著名大学之一, 主要就是因为她培养出了一大批德才兼备的优秀毕业生. 他们志向高远、基础扎实、综合素质高、创新能力强, 在国内外科技、经济、教育等领域做出了杰出的贡献, 为中国科大赢得了“科技英才的摇篮”的美誉.

2008 年 9 月, 胡锦涛总书记为中国科大建校五十周年发来贺信, 信中称赞说: 半个世纪以来, 中国科学技术大学依托中国科学院, 按照全院办校、所系结合的方针, 弘扬红专并进、理实交融的校风, 努力推进教学和科研工作的改革创新, 为党和国家培养了一大批科技人才, 取得了一系列具有世界先进水平的原创性科技成果, 为推动我国科教事业发展和社会主义现代化建设做出了重要贡献.

据统计, 中国科大迄今已毕业的 5 万人中, 已有 42 人当选中国科学院和中国工程院院士, 是同期 (自 1963 年以来) 毕业生中当选院士数最多的高校之一. 其中, 本科毕业生中平均每 1000 人就产生 1 名院士和七百多名硕士、博士, 比例位居全国高校之首. 还有众多的中青年才俊成为我国科技、企业、教育等领域的领军人物和骨干. 在历年评选的“中国青年五四奖章”获得者中, 作为科技界、科技创新型企业界青年才俊代表, 科大毕业生已连续多年榜上有名, 获奖总人数位居全国高校前列. 鲜为人知的是, 有数千名优秀毕业生踏上国防战线, 为科技强军做出了重要贡献, 涌现出二十多名科技将军和一大批国防科技中坚.

为反映中国科大五十年来人才培养成果，展示毕业生在科学研究中的最新进展，学校决定在建校五十周年之际，编辑出版《中国科学技术大学校友文库》，于2008 年 9 月起陆续出书，校庆年内集中出版 50 种. 该《文库》选题经过多轮严格的评审和论证，入选书稿学术水平高，已列为“十一五”国家重点图书出版规划.

入选作者中，有北京初创时期的毕业生，也有意气风发的少年班毕业生；有“两院”院士，也有 IEEE Fellow；有海内外科研院所、大专院校的教授，也有金融、IT 行业的英才；有默默奉献、矢志报国的科技将军，也有在国际前沿奋力拼搏的科研将才；有“文革”后留美学者中第一位担任美国大学系主任的青年教授，也有首批获得新中国博士学位的中年学者 …… 在母校五十周年华诞之际，他们通过著书立说的独特方式，向母校献礼，其深情厚意，令人感佩!

近年来，学校组织了一系列关于中国科大办学成就、经验、理念和优良传统的总结与讨论. 通过总结与讨论，我们更清醒地认识到，中国科大这所新中国亲手创办的新型理工科大学所肩负的历史使命和责任. 我想，中国科大的创办与发展，首要的目标就是围绕国家战略需求，培养造就世界一流科学家和科技领军人才. 五十年来，我们一直遵循这一目标定位，有效地探索了科教紧密结合、培养创新人才的成功之路，取得了令人瞩目的成就，也受到社会各界的广泛赞誉.

成绩属于过去，辉煌须待开创. 在未来的发展中，我们依然要牢牢把握“育人是大学第一要务”的宗旨，在坚守优良传统的基础上，不断改革创新，提高教育教学质量，早日实现胡锦涛总书记对中国科大的期待：瞄准世界科技前沿，服务国家发展战略，创造性地做好教学和科研工作，努力办成世界一流的研究型大学，培养造就更多更好的创新人才，为夺取全面建设小康社会新胜利、开创中国特色社会主义事业新局面贡献更大力量.

是为序.

2008 年 9 月

Preface

Computational intelligence techniques are ubiquitous and helpful for solving problems in various research fields, e.g., bioinformatics, computer vision research, database systems, multimedia, privacy data mining, and software engineering. The successes of computational intelligence techniques for various applications have especially been witnessed by the last thirty years. USTC alumnus contributed a lot of significant results in this society and immensely promoted the development of this society. This book offers a venue to present innovative techniques in computational intelligence and relevant applications from alumnus of USTC. Below we present the motivation of this book and then give an overview of the chapters included.

The book on computational intelligence, a part of a book series in electrical electronic engineering and computer science for promoting the national and international reputations of USTC, reporting the cutting-edge and topical research results from alumnus of USTC, and arousing sense of belongings among members of the USTC community in commemoration of its 50th anniversary.

More than ten high quality chapters from USTC alumnus were accepted from a number of submissions. Accepted chapters covered a wide range of topics in computational intelligence in terms of theories and related applications, from the following three aspects: first developing novel techniques in computational intelligence, second defining new research problems, which can be cleared up by techniques in computational intelligence, and third investigating new techniques in computational intelligence to enhance the performances of problems in various research areas.

Below we provide an overview of the chapters included.

This book starts from a review of the review of adaptive particle filters in computational intelligence (Adaptive Particle Filters). This review covers recent and ongoing developments in adaptive particle filters, which are a set of versatile approximate nonlinear Bayesian filtering techniques based on sequential Monte-Carlo simulations. Advantages of adaptive particle filters have been demonstrated in various applications, e.g., video tracking, signal processing, and nonlinear analysis. Then two techniques for content-based image retrieval (CBIR) are presented in the Chapter 2 (Feature Localization and Shape Indexing for Content-Based Image Retrieval), namely, the use of locales and shape indexes. Failure prediction has long been regarded as a challenging research problem, mainly due to the lack of realistic failure data from actual production systems. In Chapter 3 (BlueGene/L Failure Analysis and Prediction Models), authors presented three simple yet effective failure prediction methods, which can predict around 80% of the memory and network failures, and 47% of the application I/O failures. Thereafter, a neuro-fuzzy technique in computational intelligence is adapted to an intrusion tolerant database system (A Neuro-Fuzzy Approach towards Adaptive Intrusion Tolerant Database Systems) for its adaptation model in order to intelligently reconfigure the intrusion tolerant database to the changing environment and efficiently resolve multiple conflict problems. Software reliability modeling plays an important role in software reliability estimation, prediction and analysis. In Chapter 5 (ANN Applications on Software Reliability), the basic artificial neural network (ANN) modeling framework is addressed with a brief introduction of the software reliability modeling background and two extended models based on this framework are introduced to show the flexibility of this approach. Chapter 6 (A New Computational Intelligent Approach to Protein Tertiary Structure Prediction) presents new methods based on the mini-threading approach for protein structure prediction. Subspace selection methods are powerful tools in computer visiOn research and serve for crucial roles in a large number of problems, e.g., object detection. In Chapter 7 (Recursive Nonparametric Discriminant Analysis for Object Detection), a new subspace selection algorithm, termed recursive nonparametric discriminant analysis (RNDA), is developed to avoid the assumption of Gaussian distributions in traditional Fisher discriminant analysis (FDA) and to alleviate the computational complexity of conventional nonparametric discriminant analysis (NDA). In Chapter 8 (On the Privacy Preserving Properties of Projection-Based Data Perturbation Techniques), authors introduce various perturbation models in privacy preserving data mining, show the characteristics of each perturbation model, and discuss up-to-date techniques threatening the privacy of each model. Bayesian networks provide a convenient framework to model the inspection effectiveness with both abstract knowledge and actual data. After that, Chapter 9 (Bayesian Networks Modeling for Software Inspection Effectiveness) addresses issues of handling the uncertainties in software inspection process to improve the inspection effectiveness based on computational intelligence techniques. Computational Intelligence (CI) and Computational Fluid Dynamics (CFD) have grown up as disparate fields that are now being reconciled. Chapter 10 (Computational Intelligence and Computational Fluid Dynamics: Integration through Smart Simulations) presents of both fields' previous relationship, current approaches to bind them together for the better appreciation of simulation selection, monitoring and output, and the future possibilities in this field. The last Chapter of this book focuses on emerging techniques for video analysis (Intelligent Video Content Analysis and Applications) and it introduces some fundamental technologies and applications, as well as some major emerging trends for intelligent video content analysis with a specific focus on content-based video analysis and search.

As we look forward to the future, we believe that to bridge the gap between computational intelligence and cognition will be a milestone for modern computational intelligence research, and it is essential to analyse and understand information processing based on the signals captured from human brain.

In summary, we would like to thank authors for their continuous efforts and enduring patience as this book came together. We would also like to thank Prof Chang Wen Chen, the Editor in Chief of the book series, for his constant and significant support. Finally, we also acknowledge the support from the USTC colleagues.

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Contents

Chapter 1

Adaptive Particle Filters

Particle filters are a set of versatile approximate nonlinear Bayesian filtering techniques based on sequential Monte-Carlo simulations. Such Monte Carlo statistical methods make it possible to conveniently implement various Bayesian estimators for many complex nonlinear non-Gaussian problems. Major developments in the field of particle filters started only about a decade ago. In recent years, considerable research efforts are being devoted into the study of theoretical aspects, design of efficient algorithms, and implementation for many practical applications. Among the most recent developments in this field are adaptive particle filters. In general, adaptive algorithms are designed to automatically learn from and adapt to the varying conditions of the underlying system dynamics, and optimally allocate and efficiently utilize the limited resources. In particular, adaptive approaches can significantly improve computational efficiency and achieve computational intelligence, which is of paramount importance for the computation-intensive particle filtering methods to realize their great potentials in a wide variety of resource-constrained practical application scenarios. In this chapter we present an overview of recent and ongoing developments in adaptive particle filters.

1.1 Bayesian Filtering for Dynamic State Estimation

1.1.1 State and Observation Models

In many applications, a sequence of unobserved random state (or signal) $\{\mathbf{s}[n] : n \in \mathbb{N}\}$, where $\mathbb{N}$ is the set of natural numbers, needs to be estimated based on a sequence of observations $\{\mathbf{z}[n] : n \in \mathbb{N}\}$. Often times, evolution of the state sequence can be modeled as the first-order Markov process; that is,

$$\mathbf{s}[n+1] = \mathbf{f}_{n+1}(\mathbf{s}[n],\ \mathbf{u}[n]), \tag{1.1}$$

where $\mathbf{f}_n(\cdot)$ is a possibly nonlinear function of the state $\mathbf{s}[n]$ and $\mathbf{u}[n]$ is the process noise (also known as driving or excitation noise). The model in (1.1) is widely known as dynamical, system, state, or state transition model.

In addition, in many applications, the observation (or measurement) at time $n+1$, $\mathbf{z}[n+1]$, may only depend on the current state $\mathbf{s}[n+1]$, corrupted by random observation noise $\boldsymbol{\gamma}[n+1]$,

$$\mathbf{z}[n+1] = \mathbf{h}_{n+1}(\mathbf{s}[n+1], \boldsymbol{\gamma}[n+1]), \tag{1.2}$$

where $\mathbf{h}_{n+1}(\cdot)$ is a possibly nonlinear function of the state $\mathbf{s}[n+1]$.

With the known statistics of the random driving and observation noises, $\mathbf{u}[n]$ and $\boldsymbol{\gamma}[n+1]$, the state and observation models in Equation (1.1) and Equation (1.2) can be readily expressed in the form of probability densities; that is, $p(\mathbf{s}[n+1] \,|\, \mathbf{s}[n])$ and $p(\mathbf{z}[n+1] \,|\, \mathbf{s}[n+1])$ for the state and observation models, respectively. Particle filtering methods are developed based on such probabilistic state and observation models.

1.1.2 Bayesian Filtering Method

Bayesian approach is well suited for estimating dynamic state sequence when the state sequence is considered random with the initial prior density $p(\mathbf{s}[0])$ and the state transition model $p(\mathbf{s}[n+1] \,|\, \mathbf{s}[n])$. In addition, filtering approach is desirable in estimating dynamic state sequence in many practical application scenarios. With filtering approach, the unknown state is estimated sequentially (rather than as a batch) as new observation data becomes available, which enables real-time processing and eliminates the need to store the complete observation data set or to reprocess the old data at every time step. From the Bayesian filtering perspective, the posterior density of the state $p(\mathbf{s}[n] \,|\, \mathbf{z}[1:n])$ is determined sequentially at every time step, given all available observation data $\mathbf{z}[1:n]$. The posterior density may be considered as the complete solution of the Bayesian estimation problem because the probability density embodies all available statistical information. In principle, the optimal Bayesian estimators of the state at every time step may be obtained from the estimated posterior density, including minimum mean-square-error (MMSE) and maximum a posteriori (MAP) estimators [16].

Sequential Bayesian filtering algorithms can be implemented with two recursive steps, predication and update [1]. The prediction step involves using the state model Equation (1.1) to derive a prior (or prediction) density of the state at one step forward via the Chapman-Kolmogorov equation,

$$p(\mathbf{s}[n+1] \,|\, \mathbf{z}[1:n]) = \int p(\mathbf{s}[n+1] \,|\, \mathbf{s}[n])\, p(\mathbf{s}[n] \,|\, \mathbf{z}[1:n])\, d\mathbf{s}[n]. \tag{1.3}$$