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人工智能

智能系统指南

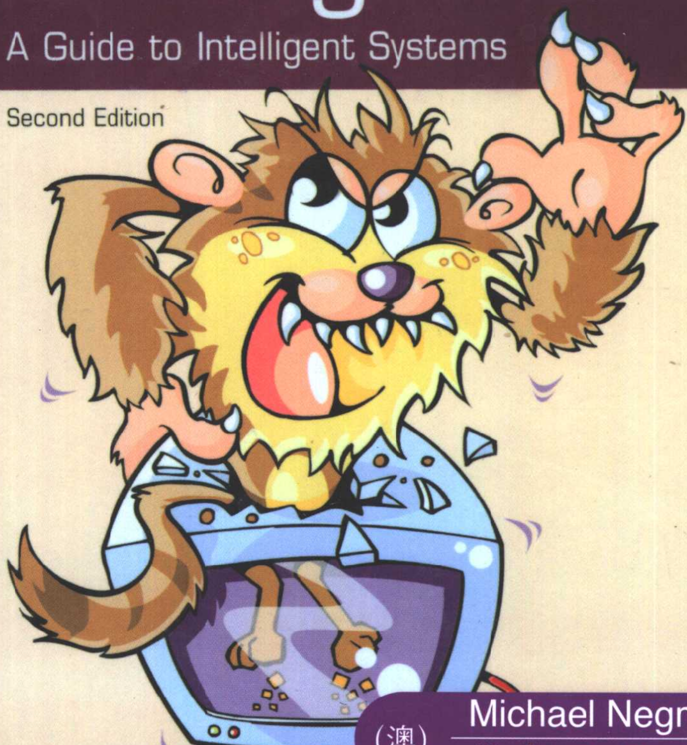
(英文版 · 第2版)

MICHAEL NEGNEVITSKY

Artificial Intelligence

A Guide to Intelligent Systems

Second Edition



(澳) Michael Negnevitsky 著
塔斯马尼亚大学

机械工业出版社
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出版者的话

文艺复兴以降，源远流长的科学精神和逐步形成的学术规范，使西方国家在自然科学的各个领域取得了垄断性的优势；也正是这样的传统，使美国在信息技术发展的六十多年间名家辈出、独领风骚。在商业化的进程中，美国的产业界与教育界越来越紧密地结合，计算机学科中的许多泰山北斗同时身处科研和教学的最前线，由此而产生的经典科学著作，不仅擘划了研究的范畴，还揭橥了学术的源变，既遵循学术规范，又自有学者个性，其价值并不会因年月的流逝而减退。

近年，在全球信息化大潮的推动下，我国的计算机产业发展迅猛，对专业人才的需求日益迫切。这对计算机教育界和出版界都既是机遇，也是挑战；而专业教材的建设在教育战略上显得举足轻重。在我国信息技术发展时间较短、从业人员较少的现状下，美国等发达国家在其计算机科学发展的几十年间积淀的经典教材仍有许多值得借鉴之处。因此，引进一批国外优秀计算机教材将对我国计算机教育事业的发展起积极的推动作用，也是与世界接轨、建设真正的世界一流大学的必由之路。

机械工业出版社华章图文信息有限公司较早意识到“出版要为教育服务”。自1998年开始，华章公司就将工作重点放在了遴选、移译国外优秀教材上。经过几年的不懈努力，我们与Prentice Hall，Addison-Wesley，McGraw-Hill，Morgan Kaufmann等世界著名出版公司建立了良好的合作关系，从它们现有的数百种教材中甄选出Tanenbaum，Stroustrup，Kernighan，Jim Gray等大师名家的一批经典作品，以“计算机科学丛书”为总称出版，供读者学习、研究及庋藏。大理石纹理的封面，也正体现了这套丛书的品位和格调。

“计算机科学丛书”的出版工作得到了国内外学者的鼎力襄助，国内的专家不仅提供了中肯的选题指导，还不辞劳苦地担任了翻译和审校的工作；而原书的作者也相当关注其作品在中国的传播，有的还专诚为其书的中译本作序。迄今，“计算机科学丛书”已经出版了近百个品种，这些书籍在读者中树立了良好的口碑，并被许多高校采用为正式教材和参考书籍，为进一步推广与发展打下了坚实的基础。

随着学科建设的初步完善和教材改革的逐渐深化，教育界对国外计算机教材的需求和应用都步入一个新的阶段。为此，华章公司将加大引进教材的力度，在“华章教育”的总规划之下出版三个系列的计算机教材：除“计算机科学丛书”之外，对影印版的教材，则单独开辟出“经典原版书库”；同时，引进全美通行的教学辅导书“Schaum's Outlines”系列组成“全美经典学习指导系列”。为了保证这三套丛书的权威性，同时也为了更好地为学校和老师们服务，华章公司聘请了中国科学院、北京大学、清华大学、国防科技大学、复旦大学、上海交通大学、南京大学、浙江大学、中国科技大学、哈尔滨工业大学、西安交通大学、中国人民大学、北京航空航天大学、北京邮电大学、中山大学、解放军理工大学、郑州大学、湖北工学院、中国国

家信息安全测评认证中心等国内重点大学和科研机构在计算机的各个领域的著名学者组成“专家指导委员会”，为我们提供选题意见和出版监督。

这三套丛书是响应教育部提出的使用外版教材的号召，为国内高校的计算机及相关专业的教学度身订造的。其中许多教材均已为M. I. T.，Stanford，U.C. Berkeley，C. M. U. 等世界名牌大学所采用。不仅涵盖了程序设计、数据结构、操作系统、计算机体系结构、数据库、编译原理、软件工程、图形学、通信与网络、离散数学等国内大学计算机专业普遍开设的核心课程，而且各具特色——有的出自语言设计者之手、有的历经三十年而不衰、有的已被全世界的几百所高校采用。在这些圆熟通博的名师大作的指引之下，读者必将在计算机科学的宫殿中由登堂而入室。

权威的作者、经典的教材、一流的译者、严格的审校、精细的编辑，这些因素使我们的图书有了质量的保证，但我们的目标是尽善尽美，而反馈的意见正是我们达到这一终极目标的重要帮助。教材的出版只是我们的后续服务的起点。华章公司欢迎老师和读者对我们的工作提出建议或给予指正，我们的联系方法如下:

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Preface

'The only way not to succeed is not to try.'

Edward Teller

Another book on artificial intelligence ... I've already seen so many of them. Why should I bother with this one? What makes this book different from the others?

Each year hundreds of books and doctoral theses extend our knowledge of computer, or artificial, intelligence. Expert systems, artificial neural networks, fuzzy systems and evolutionary computation are major technologies used in intelligent systems. Hundreds of tools support these technologies, and thousands of scientific papers continue to push their boundaries. The contents of any chapter in this book can be, and in fact is, the subject of dozens of monographs. However, I wanted to write a book that would explain the basics of intelligent systems, and perhaps even more importantly, eliminate the fear of artificial intelligence.

Most of the literature on artificial intelligence is expressed in the jargon of computer science, and crowded with complex matrix algebra and differential equations. This, of course, gives artificial intelligence an aura of respectability, and until recently kept non-computer scientists at bay. But the situation has changed!

The personal computer has become indispensable in our everyday life. We use it as a typewriter and a calculator, a calendar and a communication system, an interactive database and a decision-support system. And we want more. We want our computers to act intelligently! We see that intelligent systems are rapidly coming out of research laboratories, and we want to use them to our advantage.

What are the principles behind intelligent systems? How are they built? What are intelligent systems useful for? How do we choose the right tool for the job? These questions are answered in this book.

Unlike many books on computer intelligence, this one shows that most ideas behind intelligent systems are wonderfully simple and straightforward. The book is based on lectures given to students who have little knowledge of calculus. And readers do not need to learn a programming language! The material in this book has been extensively tested through several courses taught by the author for the past decade. Typical questions and suggestions from my students influenced the way this book was written.

The book is an introduction to the field of computer intelligence. It covers rule-based expert systems, fuzzy expert systems, frame-based expert systems, artificial neural networks, evolutionary computation, hybrid intelligent systems and knowledge engineering.

In a university setting, this book provides an introductory course for undergraduate students in computer science, computer information systems, and engineering. In the courses I teach, my students develop small rule-based and frame-based expert systems, design a fuzzy system, explore artificial neural networks, and implement a simple problem as a genetic algorithm. They use expert system shells (Leonardo, XpertRule, Level5 Object and Visual Rule Studio), MATLAB Fuzzy Logic Toolbox and MATLAB Neural Network Toolbox. I chose these tools because they can easily demonstrate the theory being presented. However, the book is not tied to any specific tool; the examples given in the book are easy to implement with different tools.

This book is also suitable as a self-study guide for non-computer science professionals. For them, the book provides access to the state of the art in knowledge-based systems and computational intelligence. In fact, this book is aimed at a large professional audience: engineers and scientists, managers and businessmen, doctors and lawyers - everyone who faces challenging problems and cannot solve them by using traditional approaches, everyone who wants to understand the tremendous achievements in computer intelligence. The book will help to develop a practical understanding of what intelligent systems can and cannot do, discover which tools are most relevant for your task and, finally, how to use these tools.

The book consists of nine chapters.

In Chapter 1, we briefly discuss the history of artificial intelligence from the era of great ideas and great expectations in the 1960s to the disillusionment and funding cutbacks in the early 1970s; from the development of the first expert systems such as DENDRAL, MYCIN and PROSPECTOR in the seventies to the maturity of expert system technology and its massive applications in different areas in the 1980s and 1990s; from a simple binary model of neurons proposed in the 1940s to a dramatic resurgence of the field of artificial neural networks in the 1980s; from the introduction of fuzzy set theory and its being ignored by the West in the 1960s to numerous 'fuzzy' consumer products offered by the Japanese in the 1980s and world-wide acceptance of 'soft' computing and computing with words in the 1990s.

In Chapter 2, we present an overview of rule-based expert systems. We briefly discuss what knowledge is, and how experts express their knowledge in the form of production rules. We identify the main players in the expert system development team and show the structure of a rule-based system. We discuss fundamental characteristics of expert systems and note that expert systems can make mistakes. Then we review the forward and backward chaining inference techniques and debate conflict resolution strategies. Finally, the advantages and disadvantages of rule-based expert systems are examined.

In Chapter 3, we present two uncertainty management techniques used in expert systems: Bayesian reasoning and certainty factors. We identify the main sources of uncertain knowledge and briefly review probability theory. We consider the Bayesian method of accumulating evidence and develop a simple expert system based on the Bayesian approach. Then we examine the certainty factors theory (a popular alternative to Bayesian reasoning) and develop an expert system based on evidential reasoning. Finally, we compare Bayesian reasoning and certainty factors, and determine appropriate areas for their applications.

In Chapter 4, we introduce fuzzy logic and discuss the philosophical ideas behind it. We present the concept of fuzzy sets, consider how to represent a fuzzy set in a computer, and examine operations of fuzzy sets. We also define linguistic variables and hedges. Then we present fuzzy rules and explain the main differences between classical and fuzzy rules. We explore two fuzzy inference techniques – Mamdani and Sugeno – and suggest appropriate areas for their application. Finally, we introduce the main steps in developing a fuzzy expert system, and illustrate the theory through the actual process of building and tuning a fuzzy system.

In Chapter 5, we present an overview of frame-based expert systems. We consider the concept of a frame and discuss how to use frames for knowledge representation. We find that inheritance is an essential feature of frame based systems. We examine the application of methods, demons and rules. Finally, we consider the development of a frame-based expert system through an example.

In Chapter 6, we introduce artificial neural networks and discuss the basic ideas behind machine learning. We present the concept of a perceptron as a simple computing element and consider the perceptron learning rule. We explore multilayer neural networks and discuss how to improve the computational efficiency of the back-propagation learning algorithm. Then we introduce recurrent neural networks, consider the Hopfield network training algorithm and bidirectional associative memory (BAM). Finally, we present self-organising neural networks and explore Hebbian and competitive learning.

In Chapter 7, we present an overview of evolutionary computation. We consider genetic algorithms, evolution strategies and genetic programming. We introduce the main steps in developing a genetic algorithm, discuss why genetic algorithms work, and illustrate the theory through actual applications of genetic algorithms. Then we present a basic concept of evolutionary strategies and determine the differences between evolutionary strategies and genetic algorithms. Finally, we consider genetic programming and its application to real problems.

In Chapter 8, we consider hybrid intelligent systems as a combination of different intelligent technologies. First we introduce a new breed of expert systems, called neural expert systems, which combine neural networks and rule-based expert systems. Then we consider a neuro-fuzzy system that is functionally equivalent to the Mamdani fuzzy inference model, and an adaptive neuro-fuzzy inference system (ANFIS), equivalent to the Sugeno fuzzy inference model. Finally, we discuss evolutionary neural networks and fuzzy evolutionary systems.

In Chapter 9, we consider knowledge engineering and data mining. First we discuss what kind of problems can be addressed with intelligent systems and introduce six main phases of the knowledge engineering process. Then we study typical applications of intelligent systems, including diagnosis, classification, decision support, pattern recognition and prediction. Finally, we examine an application of decision trees in data mining.

The book also has an appendix and a glossary. The appendix provides a list of commercially available AI tools. The glossary contains definitions of over 250 terms used in expert systems, fuzzy logic, neural networks, evolutionary computation, knowledge engineering and data mining.

I hope that the reader will share my excitement on the subject of artificial intelligence and soft computing and will find this book useful.

The website can be accessed at: http://www.booksites.net/negnevitsky

Michael Negnevitsky
Hobart, Tasmania, Australia
February 2001

Preface to the second edition

The main objective of the book remains the same as in the first edition – to provide the reader with practical understanding of the field of computer intelligence. It is intended as an introductory text suitable for a one-semester course, and assumes the students have no programming experience.

In terms of the coverage, in this edition we demonstrate several new applications of intelligent tools for solving specific problems. The changes are in the following chapters:

- In Chapter 2, we introduce a new demonstration rule-based expert system, MEDIA ADVISOR.
- In Chapter 9, we add a new case study on classification neural networks with competitive learning.
- In Chapter 9, we introduce a section 'Will genetic algorithms work for my problem?'. The section includes a case study with the travelling salesman problem.
- Also in Chapter 9, we add a new section 'Will a hybrid intelligent system work for my problem?'. This section includes two case studies: the first covers a neuro-fuzzy decision-support system with a heterogeneous structure, and the second explores an adaptive neuro-fuzzy inference system (ANFIS) with a homogeneous structure.

Finally, we have expanded the book's references and bibliographies, and updated the list of AI tools and vendors in the appendix.

Michael Negnevitsky
Hobart, Tasmania, Australia
January 2004

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I am also very grateful to numerous reviewers of my book for their comments and helpful suggestions, and to the Pearson Education editors, particularly Keith Mansfield, Owen Knight and Liz Johnson, who led me through the process of publishing this book.

I also thank my undergraduate and postgraduate students from the University of Tasmania, especially my former Ph.D. students Tan Loc Le, Quang Ha and Steven Carter, whose desire for new knowledge was both a challenge and an inspiration to me.

I am indebted to Professor Stephen Grossberg from Boston University, Professor Frank Palis from the Otto-von-Guericke-Universität Magdeburg, Germany, Professor Hiroshi Sasaki from Hiroshima University, Japan and Professor Walter Wolf from the Rochester Institute of Technology, USA for giving me the opportunity to test the book's material on their students.

I am also truly grateful to Dr Vivienne Mawson and Margaret Eldridge for proof-reading the draft text.

Although the first edition of this book appeared just two years ago, I cannot possibly thank all the people who have already used it and sent me their comments. However, I must acknowledge at least those who made especially helpful suggestions: Martin Beck (University of Plymouth, UK), Mike Brooks (University of Adelaide, Australia), Genard Catalano (Columbia College, USA), Warren du Plessis (University of Pretoria, South Africa), Salah Amin Elewa (American University, Egypt), John Fronckowiak (Medaille College, USA), Lev Goldfarb (University of New Brunswick, Canada), Susan Haller (University of Wisconsin, USA), Evor Hines (University of Warwick, UK), Philip Hingston (Edith Cowan University, Australia), Sam Hui (Stanford University, USA), David Lee (University of Hertfordshire, UK), Leon Reznik (Rochester Institute of Technology, USA), Simon Shiu (Hong Kong Polytechnic University), Thomas Uthmann (Johannes Gutenberg-Universität Mainz, Germany), Anne Venables (Victoria University, Australia), Brigitte Verdonk (University of Antwerp, Belgium), Ken Vollmar (Southwest Missouri State University, USA) and Kok Wai Wong (Nanyang Technological University, Singapore).

Contents

Introduction to knowledge-based intelligent systems

1

In which we consider what it means to be intelligent and whether machines could be such a thing.

1.1 Intelligent machines, or what machines can do

Philosophers have been trying for over two thousand years to understand and resolve two big questions of the universe: how does a human mind work, and can non-humans have minds? However, these questions are still unanswered.

Some philosophers have picked up the computational approach originated by computer scientists and accepted the idea that machines can do everything that humans can do. Others have openly opposed this idea, claiming that such highly sophisticated behaviour as love, creative discovery and moral choice will always be beyond the scope of any machine.

The nature of philosophy allows for disagreements to remain unresolved. In fact, engineers and scientists have already built machines that we can call 'intelligent'. So what does the word 'intelligence' mean? Let us look at a dictionary definition.

1 Someone's intelligence is their ability to understand and learn things.
2 Intelligence is the ability to think and understand instead of doing things by instinct or automatically.

(Essential English Dictionary, Collins, London, 1990)

Thus, according to the first definition, intelligence is the quality possessed by humans. But the second definition suggests a completely different approach and gives some flexibility; it does not specify whether it is someone or something that has the ability to think and understand. Now we should discover what thinking means. Let us consult our dictionary again.

Thinking is the activity of using your brain to consider a problem or to create an idea.

(Essential English Dictionary, Collins, London, 1990)

So, in order to think, someone or something has to have a brain, or in other words, an organ that enables someone or something to learn and understand things, to solve problems and to make decisions. So we can define intelligence as 'the ability to learn and understand, to solve problems and to make decisions'.

The very question that asks whether computers can be intelligent, or whether machines can think, came to us from the 'dark ages' of artificial intelligence (from the late 1940s). The goal of artificial intelligence (AI) as a science is to make machines do things that would require intelligence if done by humans (Boden, 1977). Therefore, the answer to the question 'Can machines think?' was vitally important to the discipline. However, the answer is not a simple 'Yes' or 'No', but rather a vague or fuzzy one. Your everyday experience and common sense would have told you that. Some people are smarter in some ways than others. Sometimes we make very intelligent decisions but sometimes we also make very silly mistakes. Some of us deal with complex mathematical and engineering problems but are moronic in philosophy and history. Some people are good at making money, while others are better at spending it. As humans, we all have the ability to learn and understand, to solve problems and to make decisions; however, our abilities are not equal and lie in different areas. Therefore, we should expect that if machines can think, some of them might be smarter than others in some ways.

One of the earliest and most significant papers on machine intelligence, 'Computing machinery and intelligence', was written by the British mathematician Alan Turing over fifty years ago (Turing, 1950). However, it has stood up well to the test of time, and Turing's approach remains universal.

Alan Turing began his scientific career in the early 1930s by rediscovering the Central Limit Theorem. In 1937 he wrote a paper on computable numbers, in which he proposed the concept of a universal machine. Later, during the Second World War, he was a key player in deciphering Enigma, the German military encoding machine. After the war, Turing designed the 'Automatic Computing Engine'. He also wrote the first program capable of playing a complete chess game; it was later implemented on the Manchester University computer. Turing's theoretical concept of the universal computer and his practical experience in building code-breaking systems equipped him to approach the key fundamental question of artificial intelligence. He asked: Is there thought without experience? Is there mind without communication? Is there language without living? Is there intelligence without life? All these questions, as you can see, are just variations on the fundamental question of artificial intelligence, Can machines think?

Turing did not provide definitions of machines and thinking, he just avoided semantic arguments by inventing a game, the Turing imitation game. Instead of asking, 'Can machines think?', Turing said we should ask, 'Can machines pass a behaviour test for intelligence?' He predicted that by the year 2000, a computer could be programmed to have a conversation with a human interrogator for five minutes and would have a 30 per cent chance of deceiving the interrogator that it was a human. Turing defined the intelligent behaviour of a computer as the ability to achieve the human-level performance in cognitive tasks. In other